614-207

Grp 4

	12-1-58	WT 20-304		4	1 (3[illegible])
✓	1-20-59	WT 20-306		3	2
✓	3-4-59	WT 20-308		4	3
✓	8-24-59	WT 20-310		4	4
✓	10-7-59	WT 20-311		4	5
	12-24-58	WT 20-312		4	6

SWT 20-308

FORCE AND PRESSURE TEST OF SEVERAL AVCO RE-ENTRY CONFIGURATIONS

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JET PROPULSION LABORATORY
California Institute of Technology
Pasadena, California
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CONTENTS

TABLES

FIGURES

PLOTS

(Plots of P/P_{stag} and C_p vs X/L at $\alpha = \varphi = 0$ deg)

Plot No.	Configuration	Mach No.	Grit	Run No.
1	111	1.32	No. 36	7
2		2.01		6
3		3.01		5
4		3.98		4
5		5.00		3
6	011	1.32	None	12
7		2.01		11
8		3.01		10
9		3.98		9
10	161	1.32	No. 36	17
11		2.01		16
12		3.01		15
13		3.98		14
14		4.76		13
15	171	1.32		22
16		2.01		21
17		3.01		20
18		3.98		19
19		4.76		18
20	071	4.76	None	23

PLOTS (Cont'd)

(Plots of $C_{P_{b_0}}$, $C_{P_{b_1}}$, $C_{P_{b_2}}$, $C_{P_{b_3}}$, $C_{P_{b_4}}$, and $C_{P_{b_5}}$ vs α at $\varphi = 0$ deg)

Plot No.	Configuration	Mach No.	Grit	Run No.
21	110	[illegible]	No. 36	36
22		[illegible]		33
23				34
24				35
25		3.01		32
26		3.98		31
27		4.76		30
28	010	4.76	None	37

(Plots of (a) C_L, (b) C_D, (c) $C_{m_{cg}}$, (d) C_N, (e) C_X, (f) $X_{C.P.}$,

and (g) $-C_{P_{b_0}}$ vs α at $\varphi = 0$ deg

29	110	Parameter	No. 36	30-36
30	010		None	37,69,70
31	130		No. 36	38,45,50,56,61
32	030		None	65,68,71
33	140		No. 36	39,46,51,57,62
34	040		None	66,67,72
35	150		No. 36	40,47-49,58,60
36	160			42,43,53,54,64
37	170			41,44,52,55,63

I. INTRODUCTION

At the request of the AVCO Manufacturing Corporation, Lawrence, Massachusetts, a force and pressure test was performed in the 20-in. Supersonic Wind Tunnel (SWT) of the Jet Propulsion Laboratory (JPL) on models of several re-entry configurations consisting of blunted cone-cylinder combinations with and without boat-tailing.

The objective of the test was to obtain experimental data for use in evaluating theoretical predictions of aerodynamic characteristics and pressure distributions on the various configurations.

The test was performed[1] at Mach numbers 1.32, 2.01, 3.01, 3.98, and 4.76, during the period July 11 through 18, 1958. Mr. Thomas B. Sellers represented the AVCO Manufacturing Corporation.

II. MODEL DESCRIPTION

Of the six aerodynamic shapes tested, three were run in both force and pressure configurations and three were run in force configurations only. The latter three differed from one another only so far as fins were concerned. All were made up of the same blunted nose cone and cylindrical afterbody. One had no fins, one had thin fins, and the third had thick fins.

The configurations which were run to obtain both force and pressure data fall into two divisions. The first division was composed of two models which again differed only in the fins. The two models were both made up of a blunted nose cone, a cylindrical center

[1]The notation used in this Report is defined in the Nomenclature.

section, and a boat-tailed afterbody. One model had no fins, while the other model had thin fins attached to the boat-tailed section. The second division contained only one model, a basic configuration consisting of a blunted nose cone, a cylindrical center section, and a flared afterbody.

A more detailed description of the six configurations may be found in the Nomenclature, in Ref. 1, in Table 1, and in Figs. 1 and 2. As illustrated by these two Figs., all models were axially symmetric, except for the fins which exhibited a cruciform placement.

III. WIND TUNNEL AND INSTRUMENTATION

Design features of the 20-in. wind tunnel permit its continuous operation in either a variable-density closed circuit or an open circuit. For the present test, it was operated as a closed-circuit tunnel. Any value of test-section Mach number between 1.32 and 5.00 may be set remotely; however, normal operation is restricted to the 20 Mach numbers between 1.32 and 5.00 for which flow survey calibrations have been made. Operation at other than calibrated Mach numbers is based upon interpolated nozzle settings and, in some instances, partial calibrations. At all Mach numbers,the test section is 20 in. high and 18 in. wide. During a given run, the air supply is maintained at a constant temperature and normally at a dew point sufficiently low to insure that dew-point effects on the data are negligible. The maximum values of dew point at which data were obtained at each Mach number are given in Table 2.

Test-section flow parameters were determined by using the Mach number, the measured supply-section stagnation pressure and temperature, and the assumption of isentropic flow in the nozzle. Table 2 presents a representative value of the test-section flow parameters for Mach numbers at which this test was performed.

Flow in the test section may be observed optically by either the shadowgraph or the schlieren technique. During this test, schlieren photographs were taken at 0, 2, 4, 8, 16, and 20 deg angle of attack.

The six-component hydraulic balance and the model support system used for this test are shown in Fig. 3. The models were sting-supported from the crescent-shaped strut carrier (see Figs. 4 and 5), which may be rotated 30 deg in pitch. The angle-of-attack range was -10 to 20 deg for the straight sting used in this test. The sting and strut carrier are protected from aerodynamic loads by a windshield which is open to the tank surrounding the balance. Flow between the test section and the balance tank is prevented by evacuating the tank to the model base pressure.

The balance system mechanically separates the model lift, drag, and side force and pitching, rolling, and yawing moments. These forces and moments are sensed by hydraulic load cells and are measured by self-balancing beams. The moments as measured are referred to a set of orthogonal axes which intersect at a point that is coincident with the center of rotation of the support system and the centerline of the test-section windows.

The range and repeatability of the balance are shown in Table 3.

For eight of the configuration 110 runs during the force portion of the test, a model-base-pressure rake was attached to the windshield (see Fig. 6) in such a manner that five base pressures were measured at various distances from the center of the model base immediately aft of the base plane. These five pressures were sensed by a single transducer which measured each pressure in turn. These data were eventually read manually from a potentiometer indicator and punched into paper tape.

During all the force runs, a single base pressure tap was monitored to insure equity between model base pressure and balance tank pressure, as mentioned earlier in this section.

Although three aerodynamic shapes were pressure tested, only two models had to be instrumented since configuration 171* is evolved simply by removing the fins from configuration 161. A total of 26 body static and 5 fin base pressures were measured on configuration 161, and all but the 5 fin base pressures were measured on configuration 171. The other pressure model, configuration 111, incorporated 40 body static taps. All pressures were sensed and recorded by a multipressure measuring system whose main components include an accurate strain-gauge type pressure transducer, multitap pressure selector valves, and a high speed encoder with punched paper tape recording (see Fig. 7).

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*See Model Nomenclature in the Nomenclature section of this Report.

IV. TEST PROCEDURE

Prior to actual test operations, measurements were made to determine the position of the model, the deflection constants, and the balance tares, as described in Section V.

During the force portion of the test, the balance tank pressure was maintained equal to the model base pressure, and data points were obtained at successive values of angle of attack. The stagnation pressure and model base pressure were recorded for all data points, and the stagnation and dew-point temperatures were read at least once each run. Balance readings were plotted vs angle of attack, and any data which appeared questionable were checked before the conclusion of the run; but even if all of the data appeared to be correct, at least one point from each run was checked. Schlieren photographs were made only during the force portion of the test and at the angles of attack mentioned in Section III. Typical examples are illustrated in Figs. 8, 9, and 10.

Since the multipressure measuring system used in this test was at that time a comparatively new piece of equipment, a mercury manometer board displaying the model pressures being measured was photographed at zero angle of attack during each pressure run. However, the accuracy and reliability of the new system proved to be such that the photographic data were not used in the reduction described in Section V.

The test was conducted in the order shown in Table 4.

V. DATA REDUCTION

The force and moment data were reduced (see Ref. 2) to dimensionless coefficients and are presented with respect to a model reference point and in two coordinate systems (see Fig. 11), specified by the AVCO Manufacturing Corporation. The model reference point was taken as the vehicle center of gravity which varied with configuration, as shown in Table 1. The pitch axis system is an orthogonal set of axes which have their origin at the model reference point and which rotate with the model in pitch and yaw, but remain fixed in roll. The tunnel wind axes are identical to the pitch axes, except that they remain fixed with respect to the tunnel.

Linear expressions derived from the deflection measurements (see Section IV) were used to determine the actual position and attitude of the model for each test point.

Three types of corrections were applied to the data, as follows:

1. In order to compensate for zero drift during the test, air-off readings with the model level were taken at frequent intervals. These air-off-zeros were then subtracted from the test data to determine values due only to aerodynamic loads.
2. Static tares, produced by unbalanced weight in the system with no air flow through the test section, were evaluated by setting the model to the attitudes to be experienced during the test and recording the balance readings. These readings were subsequently subtracted from the readings obtained during the test.

3. During each run, the balance tank pressure was very closely matched with the model base pressure, as discussed in Section III. Where a descrepancy between the two pressures did exist, a term was added to the data reduction to eliminate any error arising therefrom.

The repeatability of the data in coefficient form is given in Table 5. Three alpha-zero data points in each run were compared with one another to determine the greatest failure of the data to repeat itself. The figures in Table 4 represent the worst ability to repeat, after ignoring 2 or 3 wild values, for each component measured at each Mach number.

The following equations were used in the reduction of the data:

$$C_N = N/qA$$

$$C_X = F_X/qA$$

$$C_{m_{cg}} = M/qAd$$

$$X_{c.p.} = X_{cg} - C_{m_{cg}}/C_N$$

$$C_L = L/qA$$

$$C_D = D/qA$$

$$C_{P_{b_i}} = \left(P_{b_i} - P_s\right)/q$$

$$P/P_{stag} = P/\left(P_{t_2}/P_{t_1}\right)P_t$$

$$C_P = \left(P - P_s\right)/q$$

where

$$P_s = \left(P_s/P_t\right)P_t$$

$$q = \left(q/P_t\right)P_t$$

A = cross-sectional area of model body cylinder, 3.457 in.^{2}

d = model body-cylinder diameter, 2.098 in.^{2}

i = a number from zero through five which indicates the radial position of any one of six base pressure taps (see Fig. 7).

VI. RESULTS

The information obtained during the test is presented in three groups of plots as shown in the plots section (see Plots 1 through 37g). The first group contains Plots 1 through 20 in which P/P_{stag} and C_P are plotted vs the model length ratio X/L. Group two is composed of Plots 21 through 28 in which $C_{P_{b_0}}$, $C_{P_{b_1}}$, $C_{P_{b_2}}$, $C_{P_{b_3}}$, $C_{P_{b_4}}$, and $C_{P_{b_5}}$ are plotted vs angle of attack. The third group contains nine families of plots, numbered 29 through 37. Each family, in turn, contains Plots a through g which are, respectively, C_L, C_D, $C_{m_{cg}}$, C_N, C_X, $X_{c.p.}$, and $C_{P_{b_0}}$ vs α.

Figures 12 through 15 are summary plots which illustrate typical effects of Mach number, configuration, and roughness (to induce boundary layer transition) on model pressures, lift, drag, pitching moment, and center of pressure location.

No attempt to analyze the data is made here. Copies of the plots and prints of the schlieren photographs were forwarded to the AVCO Manufacturing Corporation, and a detailed analysis will be performed there.

REFERENCES

1. Sellers, T. B., Wind Tunnel Pre-Test Report for the Jet Propulsion Laboratory 20-in. Supersonic Wind Tunnel. AVCO Manufacturing Corporation, Lawrence, Massachusetts, May 22, 1958.

2. Equations for Wind Tunnel Force Data Reduction, Internal Memorandum SWT G-T3. Jet Propulsion Laboratory, Pasadena, California, April 19, 1957.

NOMENCLATURE

Data Reduction Nomenclature[2]

A = reference area, 3.4570 in.^{2}

C_D = drag force coefficient, D/qA

cg = defined model center of gravity

C_L = lift force coefficient, L/qA

$C_{m_{cg}}$ = pitching moment coefficient, M/qAd

C_N = normal force coefficient, N/qA

C_P = model local static pressure coefficient, $(P - P_s)/q$

$C_{P_{b_i}}$ = model base pressure coefficient, $(P_{b_i} - P_s)/q$

C_X = chord force coefficient, F_X/qA

d = reference length, 2.098 in.

D = drag force (not corrected for base pressure), lb

F_X = chord force (not corrected for base pressure), lb

i = a subscript number from 0 thru 5, which indicates the radial position of any one of six base pressure taps (see Fig. 7)

L = lift force, lb

M = Mach number

M = pitching moment, in.-lb

N = normal force, lb

P = model local static pressure, lb/in.^{2}

P_{b_i} = model base pressure, lb/in.^{2}

[2]Positive directions for force and moment coefficients are given in Fig. 11.

NOMENCLATURE (Cont'd)

P_s = free-stream static pressure, lb/in.^{2}

P_{stag} = test-section stagnation pressure behind a normal shock wave, lb/in.^{2}

P_t = tunnel supply section total pressure, lb/in.^{2}

P_{t_2}/P_{t_1} = ratio of total pressure behind a normal shock wave to total pressure before the normal shock wave

q = free-stream dynamic pressure, lb/in.^{2}

X_{cg} = model center of gravity location, inches aft of nose

$X_{C.P.}$ = center of pressure location, inches aft of nose

X/L = ratio of pressure tap distance aft of nose to total model length

α = model angle of attack, deg

φ = model roll angle, deg

Model Nomenclature[3]

$$N_a^b \quad B^c \quad F_e^d \quad \text{or} \quad N_a^b \quad B_B^c \quad f^g$$

N = nose configuration

a = nose radius in cylinder radii

b = nose cone angle in deg

B = cylindrical body

c = cylinder length in cylinder diameters

B = boat-tailed afterbody

[3]See Figs. 1 and 2 for illustrations of models.

NOMENCLATURE (Cont'd)

F = flare

d = flare angle in deg

e = flare length in cylinder diameters

f = fin

g = fin thickness in cylinder diameters

Configuration Nomenclature

Configuration	Code	Explanation
$N^{11}_{0.3}B^{1.5}F^{15}_{0.80}$	X10	(1) First digit indicates roughness: 1 = grit applied; 0 = grit removed
$N^{11}_{0.3}B^{1.5}F^{15}_{0.80}$	X11	
$N^{11}_{0.3}B^{3.0}$	X30	(2) Second digit indicates aerodynamic configuration, as in table at left
$N^{11}_{0.3}B^{3.0}f^{0.07}$	X40	
$N^{11}_{0.3}B^{3.0}f^{0.71}$	X50	(3) Third digit indicates instrumentation: 1 = pressure; 0 = force
$N^{11}_{0.3}B^{3.0}_{B}f^{0.07}$	X60	
$N^{11}_{0.3}B^{3.0}_{B}f^{0.07}$	X61	
$N^{11}_{0.3}B^{3.0}_{B}$	X70	
$N^{11}_{0.3}B^{3.0}_{B}$	X71	

TABLE 1. MODEL DIMENSIONS

Configuration Code	X10 X11	X30	X40	X50	X60 X61	X70 X71
Length						
Overall	8.742	10.102	10.102	10.102	10.102	10.102
Nose	3.914	3.914	3.914	3.914	3.914	3.914
Cylindrical Body	3.145	6.188	6.188	6.188	6.188	6.188
Flare	1.683	-----	-----	-----	-----	-----
Boat-tail	-----	-----	-----	-----	2.098	2.098
Fin	-----	-----	2.098	2.098	2.098	-----
Diameter						
Cylindrical Body	2.098	2.098	2.098	2.098	2.098	2.098
Flare Base	3.000	-----	-----	-----	-----	-----
Boat-tail Base	-----	-----	-----	-----	1.049	1.049
Radius						
Nose	0.349	0.349	0.349	0.349	0.349	0.349
Fin Base (at Fin ℄	-----	-----	1.574	1.504	1.574	-----
Thickness						
Fin	-----	-----	0.140	1.483	0.140	-----
Conical Half Angle						
Nose	11	11	11	11	11	11
Flare	15	--	--	--	--	--
Boat-tail	--	--	--	--	14	14

TABLE 1 (Cont'd)

Configuration Code	X10 X11	X30	X40	X50	X60 X61	X70 X71
CG Location Aft of Nose	5.979	5.612	5.612	5.612	5.612	5.612

Consult Ref. 1 for pressure port locations.

All dimensions in deg and in model scale in. and in^2; no scale given; see Configuration Nomenclature and Fig. 2.

TABLE 2. AVERAGE AERODYNAMIC PARAMETERS

Parameter	Mach Number				
	1.32	2.01	3.01	3.98	4.76
Static pressure (psia)	7.00	3.26	0.78	0.33	0.16
Stagnation pressure (psia)	20.22	26.00	28.89	49.11	63.56
Dynamic pressure (psia)	8.76	9.24	4.92	3.76	2.53
Reynolds number (per in. x 10^{-6})	0.475	0.500	0.338	0.337	0.287
Max dew point (°F)	+4	+3	+4	+8	+12
Mach-number variation along centerline	+0.002 -0.003	+0.004 +0.004	+0.003 -0.004	+0.005 -0.006	+0.004 -0.008
Max flow-angle variation along centerline deg	+0.02 -0.02	+0.08 -0.11	+0.08 -0.03	+0.13 -0.01	-0.01 -0.07
Max pressure variation along centerline ($\Delta p/p$)	0.004	0.006	0.006	0.007	0.010

TABLE 3. BALANCE RANGE AND REPEATABILITY

Component	Low Range			High Range		
	Maximum Positive	Maximum Negative	Repeat-ability	Maximum Positive	Maximum Negative	Repeat-ability
Lift (lb)	52	12	±0.05	320	120	±0.2
Drag (lb)	25	20	±0.05	225	325	±0.2
Side force (lb)	30	30	±0.05	30	100	±0.2
Pitching moment (in.-lb)	325	425	±0.50	3500	1100	±2.0
Yawing moment (in.-lb)	200	440	±0.50	1800	2500	±2.0
Rolling moment (in.-lb)	440	200	±0.50	2800	2000	±2.0

TABLE 4. RUN SUMMARY

Date (1958)	Run No.	Configuration Code	Mach No.	α (deg)	Grit	P_b	Rake	Remarks
7-11	1	110	-	-	-	-	-	Static tare
7-11	2	130	-	-	-	-	-	Static tare
7-14	3	111	5.00	B	No. 36	Off		
	4		3.98					
	5		3.01					
	6		2.01					
	7		1.32					
	8	011	5.00		None		-	No data; no flow
	9		3.98					
	10		3.01					
	11		2.01					
	12		1.32					
7-15	13	161	4.76		No. 36			
	14		3.98					
	15		3.01					
	16		2.01					
	17		1.32					
	18	171	4.76					
	19		3.98					
	20		3.01					
	21		2.01					
	22		1.32					
	23	071	4.76		None			

TABLE 4 (Cont'd)

Date (1958)	Run No.	Configuration Code	Mach No.	α (deg)	Grit	P_b	Rake	Remarks
7-15	24	130	-	-	-	-	-	Static tare
	25	160	-	-	-	-	-	Static tare
	26	150	-	-	-	-	-	Static tare
	27	140	-	-	-	-	-	Static tare
	28	170	-	-	-	-	-	Static tare
	29	110	-	-	-	-	-	Static tare
7-16	30		4.76	A	No. 36	On		
	31		3.98					
	32		3.01					
	33		2.01				-	Rake grounded at α = 11 deg
	34							
	35						-	Reduced P_t
	36		1.32					
	37	010	4.76		None			
	38	130			No. 36	Off		
	39	140						
	40	150						
	41							
7-17	42	160						
	43	160	3.98					
	44	170						
	45	130						

TABLE 4 (Cont'd)

Date (1958)	Run No.	Configuration Code	Mach No.	α (deg)	Grit	P_b	Rake	Remarks
7-17	46	140	3.98	A	No. 36	Off		
	47	150	3.98					
	48	150	3.01					
	49	150						
	50	130						
	51	140						
	52	170						
	53	160						
	54	160	1.32				-	Data questionable
	55	170					-	Data questionable
	56	130					-	Data questionable
	57	140						
	58	150						
	59	120	-	-	-	-	-	Static tare
7-18	60	150	2.01	A	No. 36	Off		
	61	130						
	62	140						
	63	170						
	64	160						
	65	030			None			
	66	040			None			

TABLE 4 (Cont'd)

Date (1958)	Run No.	Configuration Code	Mach No.	α (deg)	Grit	P_b	Rake	Remarks
7-18	67	040	1.32	A	None	Off		
↓	68	030	↓	A	↓	↓		
↓	69	010	↓	-	↓	↓	-	Special α schedule
↓	70	010	4.76	A	↓	↓	-	Repeat of run 37
↓	71	030	↓	↓	↓	↓		
↓	72	040	↓	↓	↓	↓		

α Schedule A: 0, -4, -2, 0, 2, 4, 8, 12, 16, 20, and 0

α Schedule B: 0, -10, -5, 5, 10, 15, and 20

TABLE 5. COEFFICIENT REPEATABILITY

Mach No.	Coefficient[c]			
	C_L^a	C_D^b	C_D^a	$C_{m_{cg}}^b$
1.32	0.008	-	0.009	0.008
2.01	0.006	-	0.009	0.008
3.01	0.006	-	0.012	0.008
3.98	0.008	0.003	-	0.011
4.76	0.012	0.002	-	0.015
4.76[d]	0.023	0.006	0.023	0.027

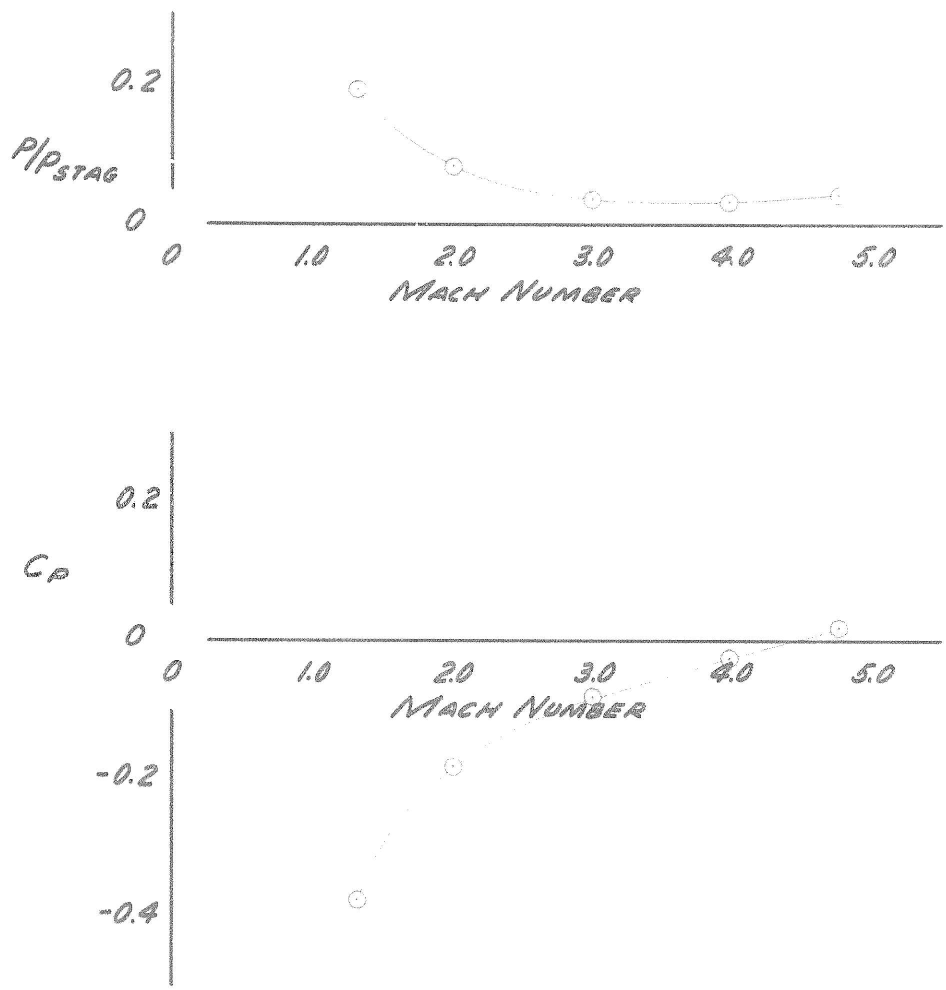
[a]High balance range used.

[b]Low balance range used.

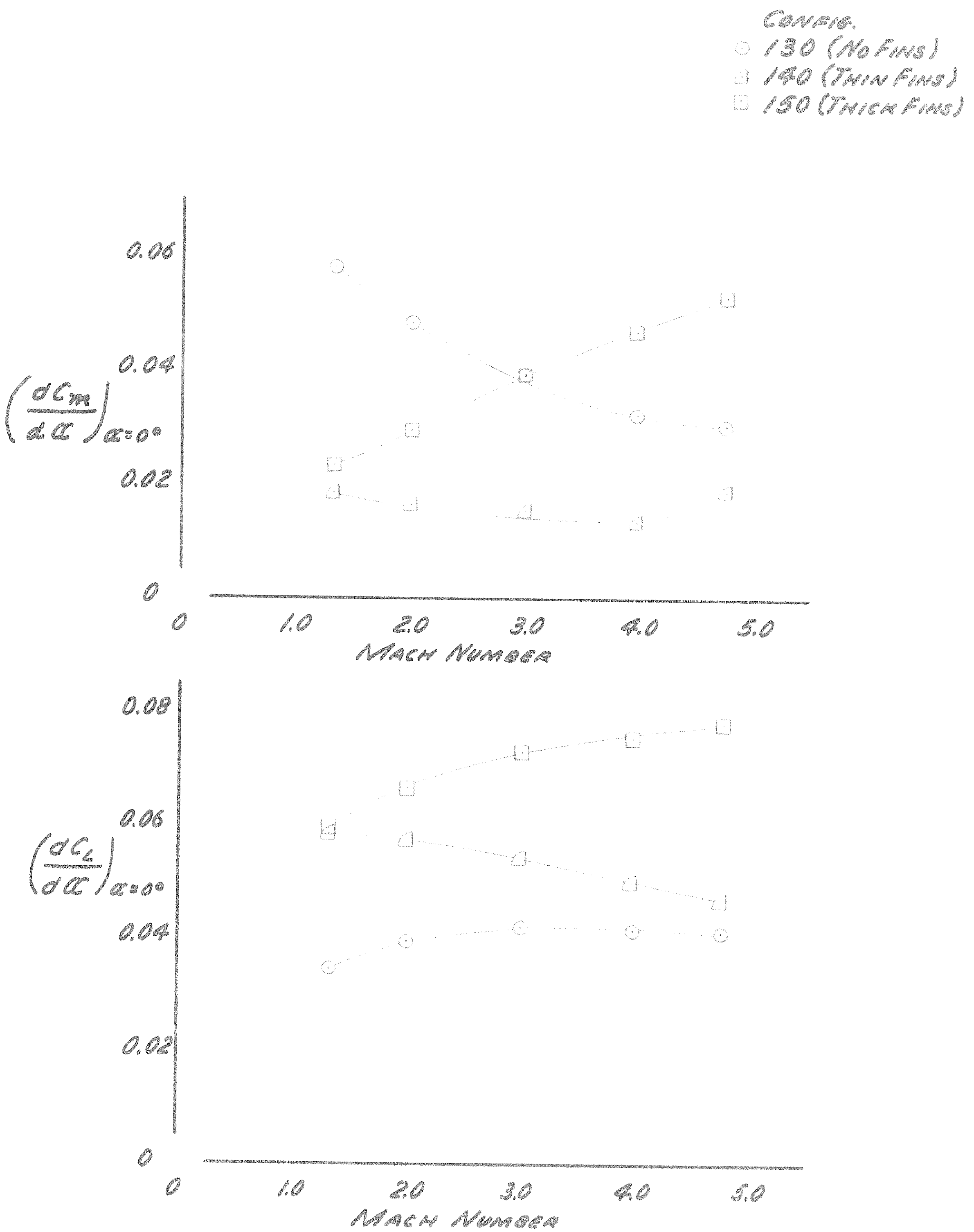
[c]Based upon the following reference areas and lengths: $S = 3.457$ in.^{2}, and $d = 2.098$ in.

[d]Based upon the Table 3 balance repeatability for the appropriate range used and the reference values given in footnote c, above.

X/L = 0.827
CONFIG.
⊙ 161

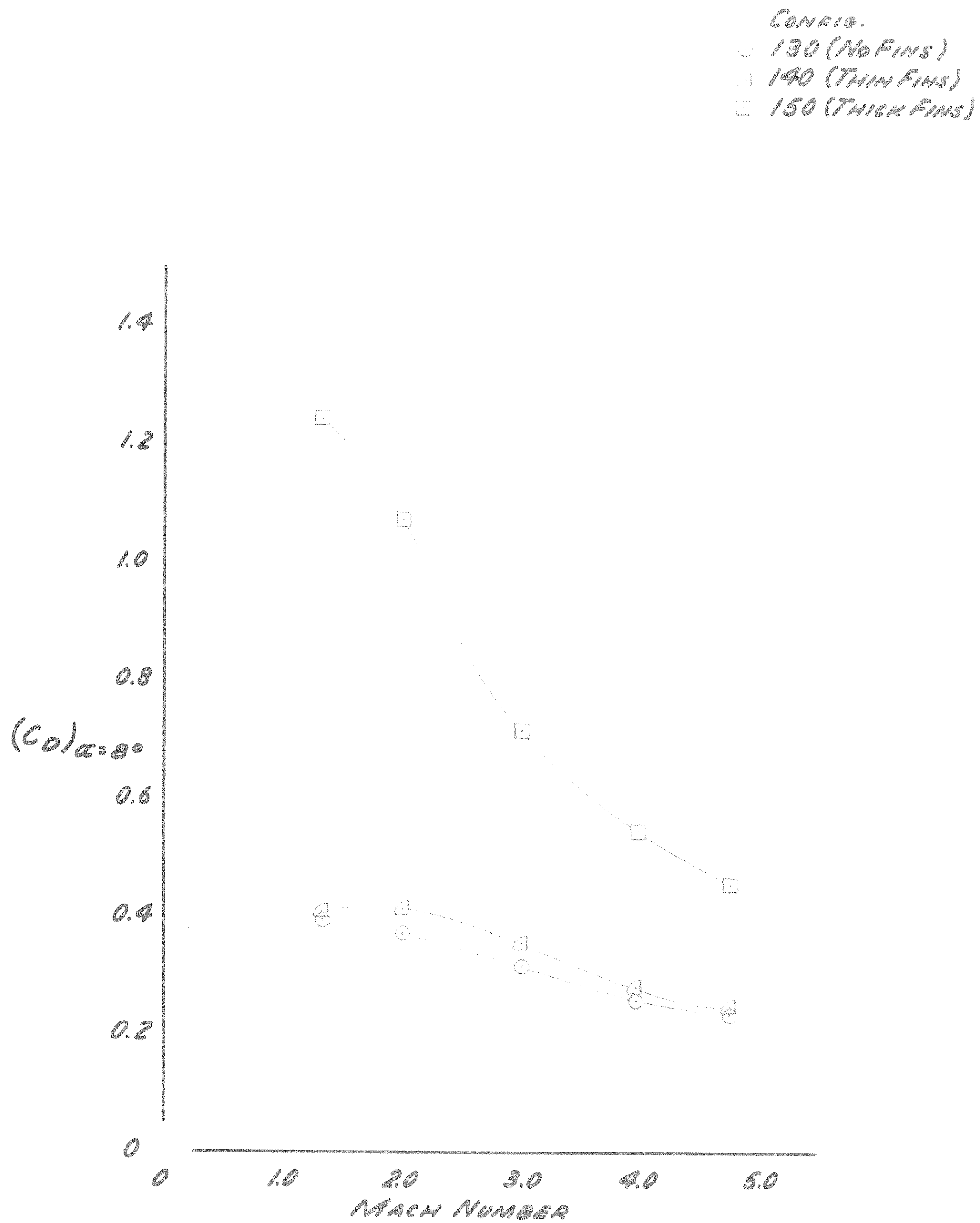


EFFECT OF MACH NUMBER ON P/p_{STAG} AND C_p FOR CONFIGURATION 161 AT $X/L = 0.827$, $\alpha = 0°$, WITH ROUGHNESS



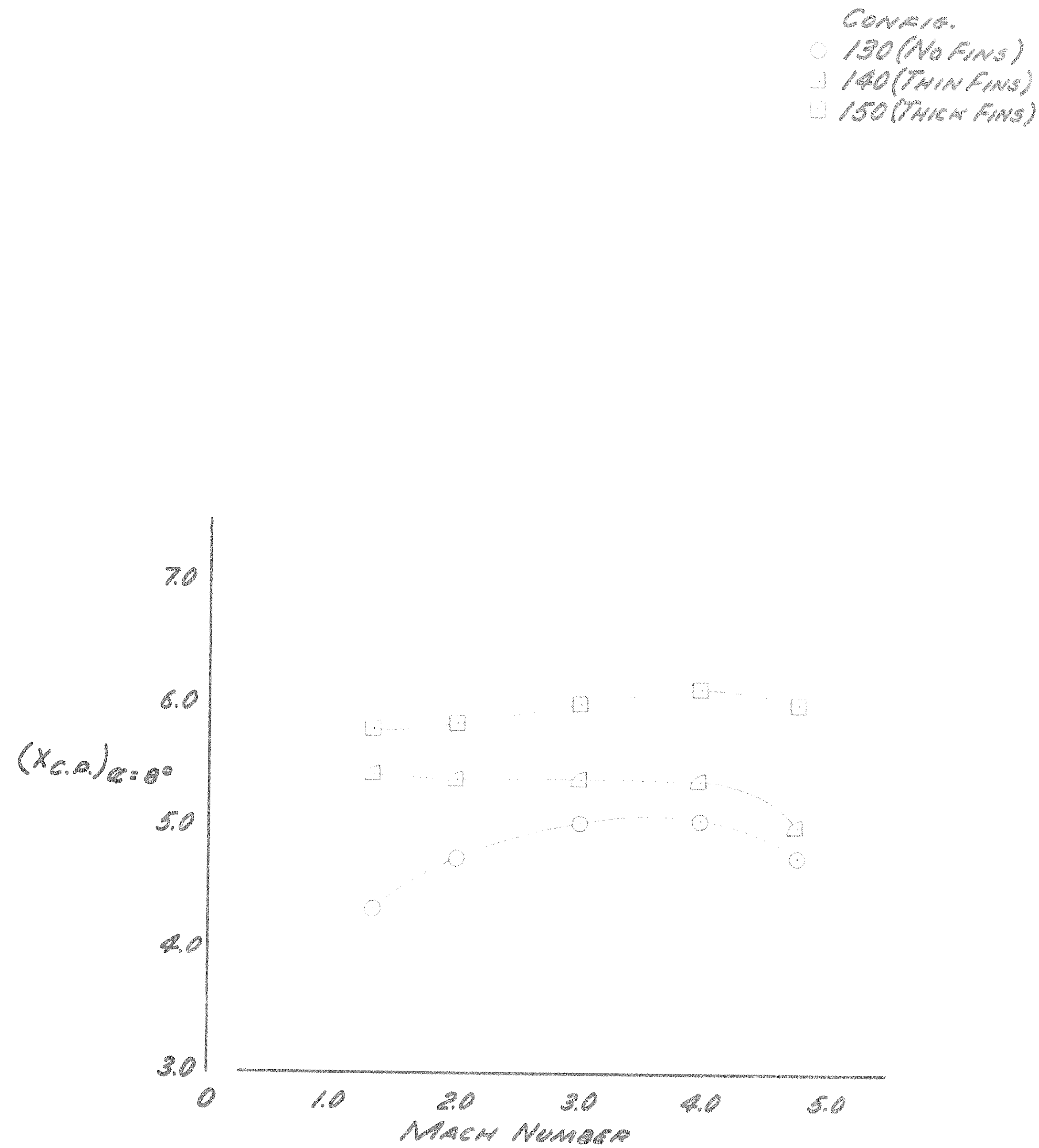
EFFECT OF MACH NUMBER AND CONFIGURATION UPON LIFT CURVE SLOPE AND PITCHING MOMENT CURVE SLOPE AT $\alpha = 0°$, $\phi = 0°$, WITH ROUGHNESS

FIGURE 13

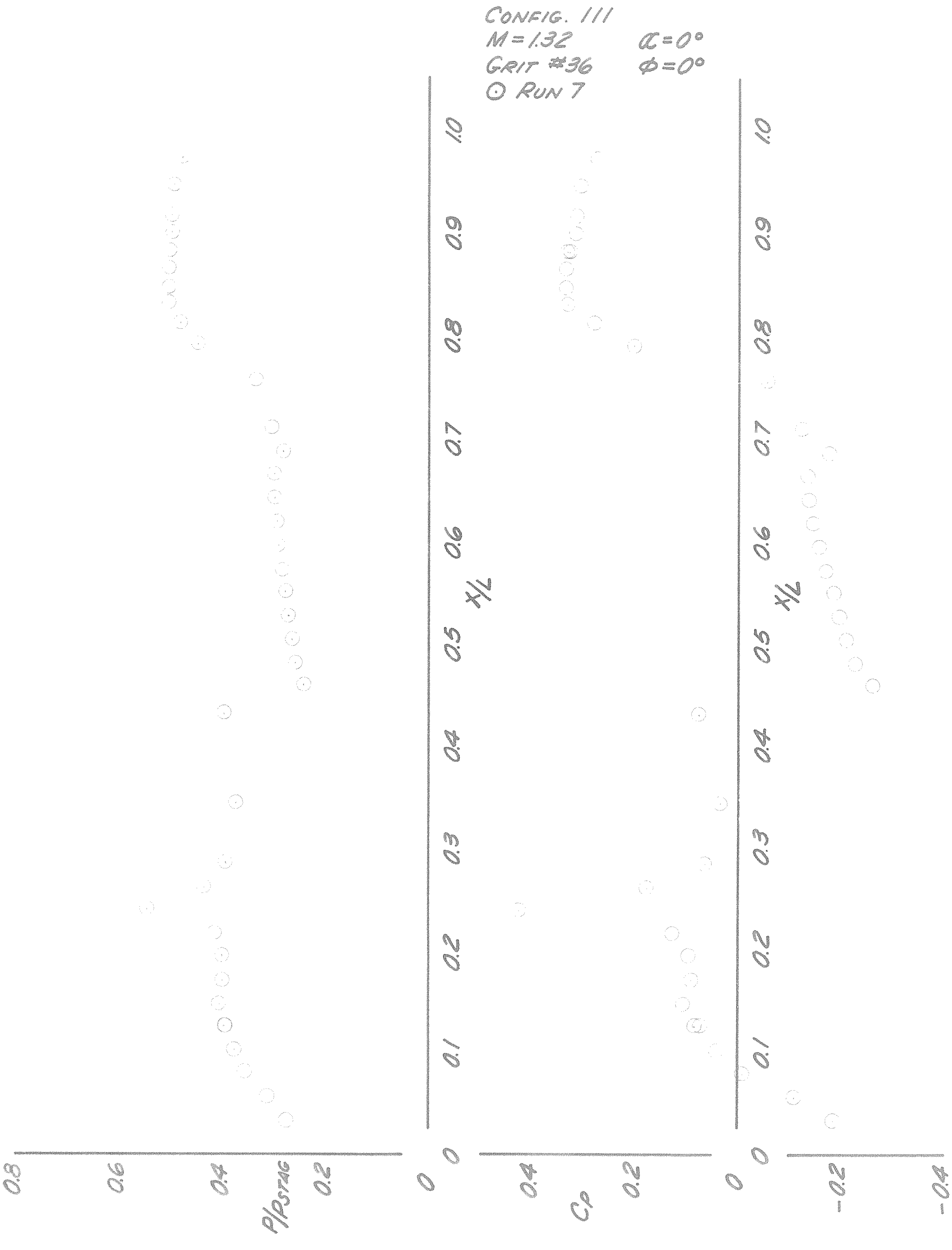


EFFECT OF MACH NUMBER AND CONFIGURATION UPON DRAG COEFFICIENT AT $\alpha = 8°$, $\phi = 0°$, WITH ROUGHNESS

SWT 20-308

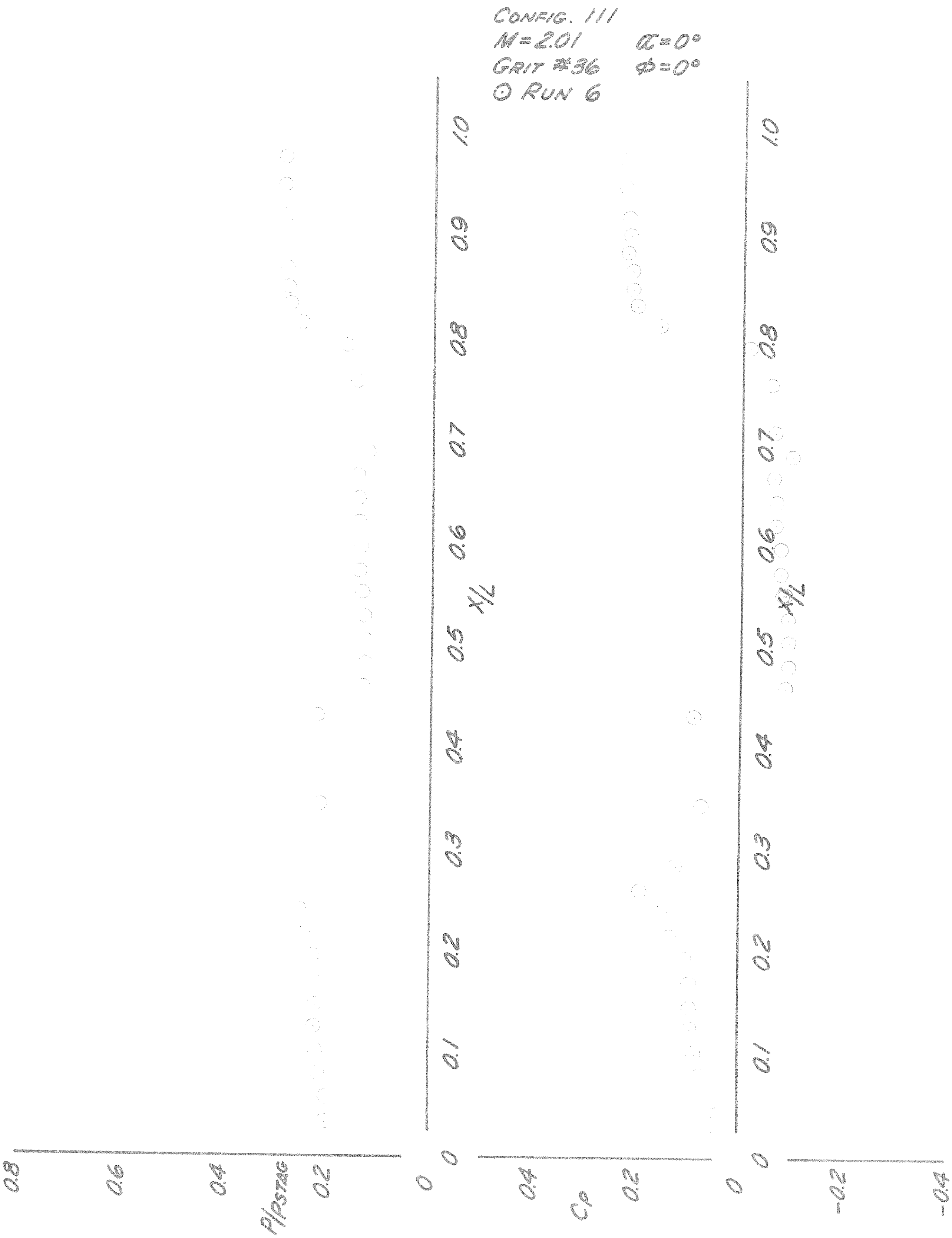


EFFECT OF MACH NUMBER AND CONFIGURATION UPON CENTER OF PRESSURE LOCATION AT $\alpha = 8°$, $\phi = 0°$, WITH ROUGHNESS

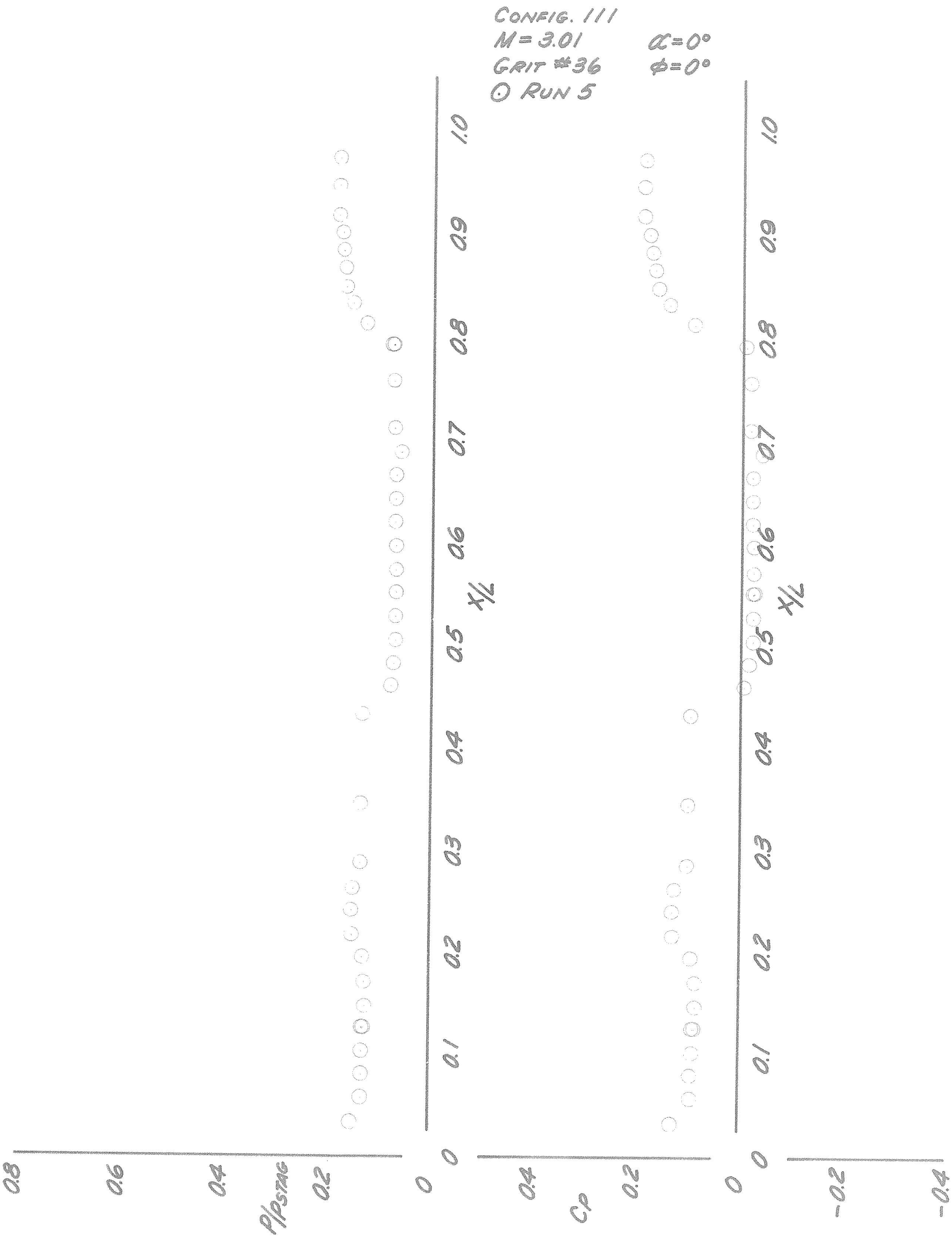

CONFIG. 111
M = 1.32
α = 0°
GRIT #36
φ = 0°
⊙ RUN 7
X/L
P/PSTAG
CP
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.8
0.6
0.4
0.2
-0.2
-0.4

PLOT 1

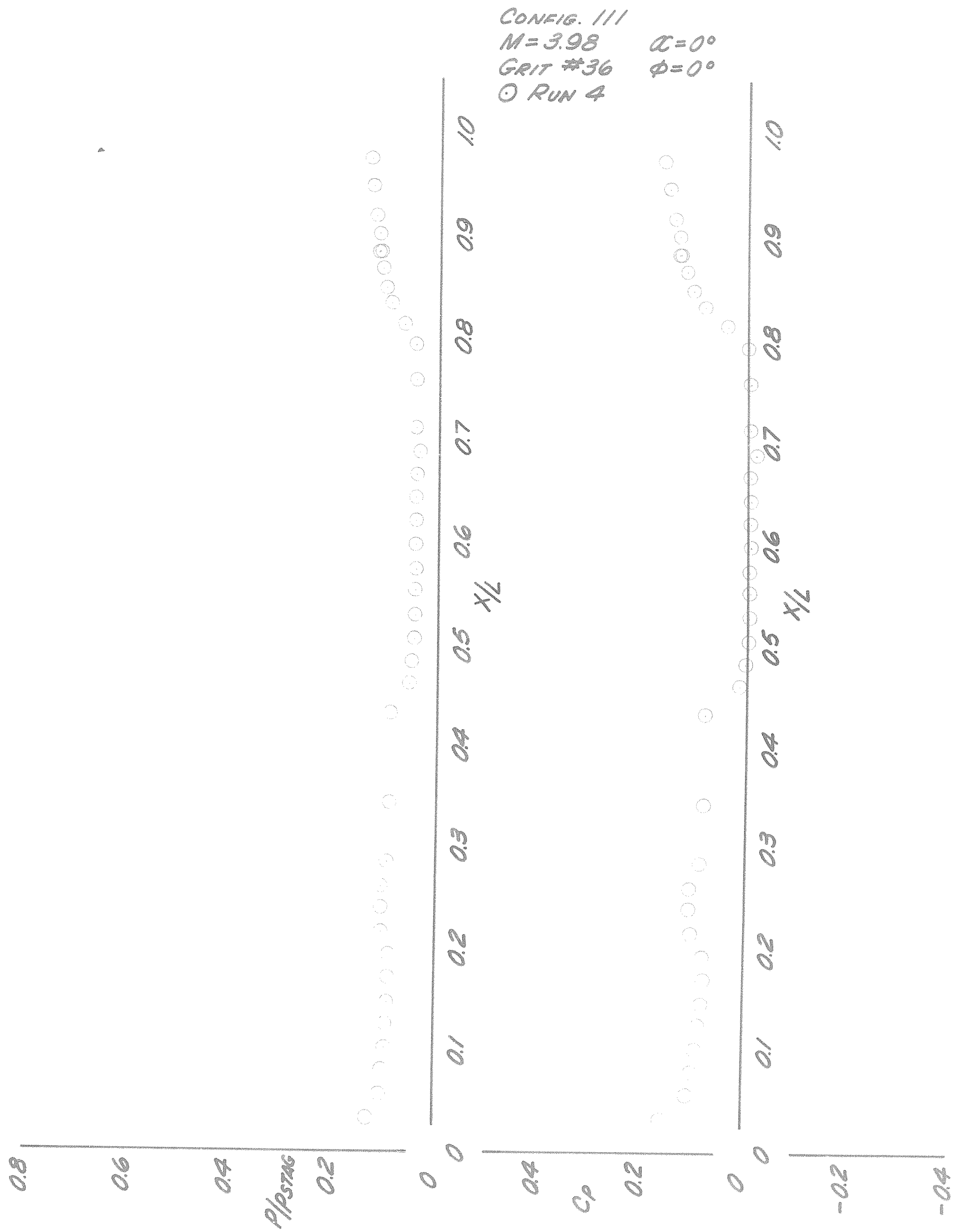
SWT 20-308



PLOT 2

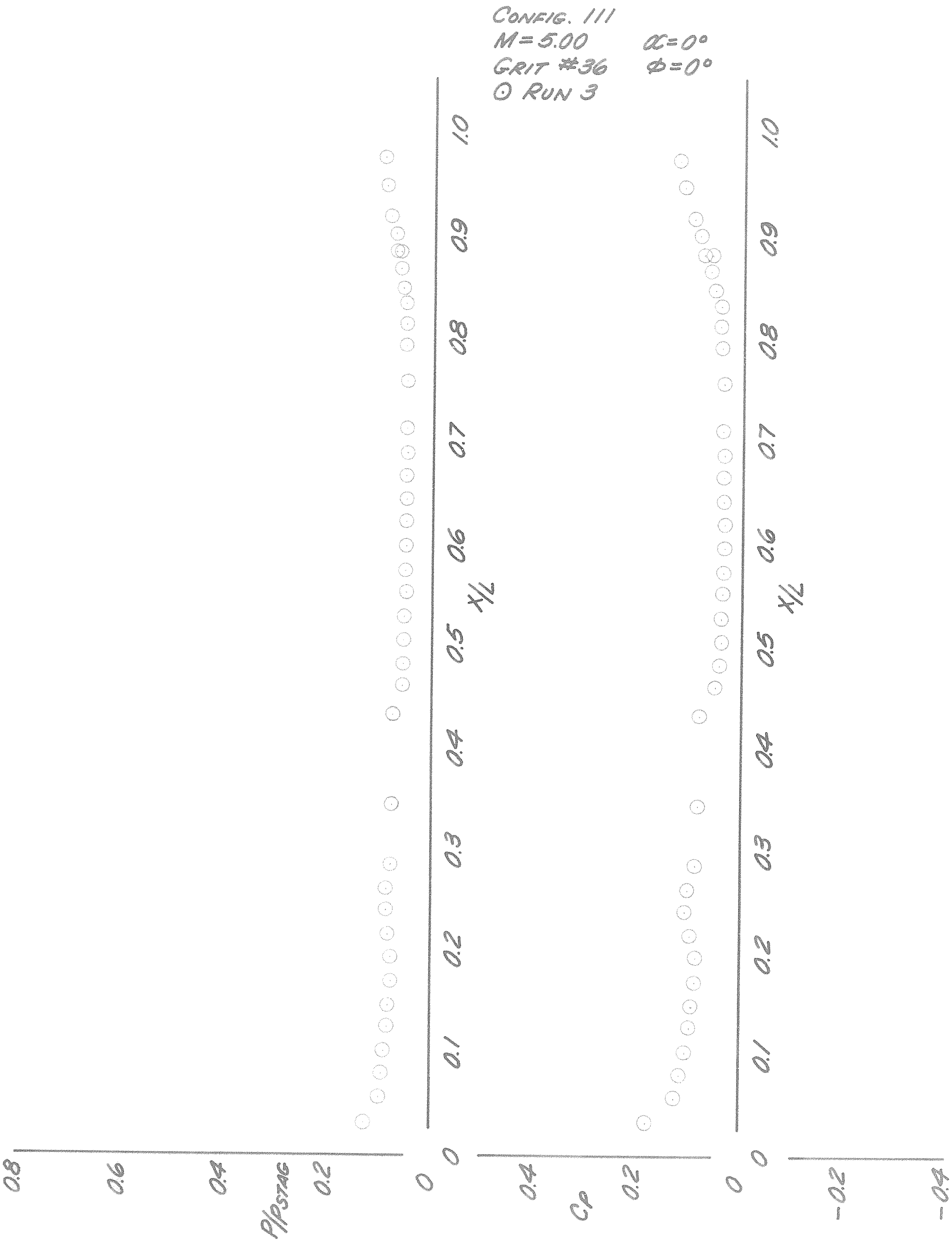

CONFIG. 111
M = 3.01
GRIT #36
α = 0°
φ = 0°
⊙ RUN 5
X/L
P/PSTAG
CP
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0.1
0.2
0.3
0.5
0.6
0.7
0.9
1.0

PLOT 3

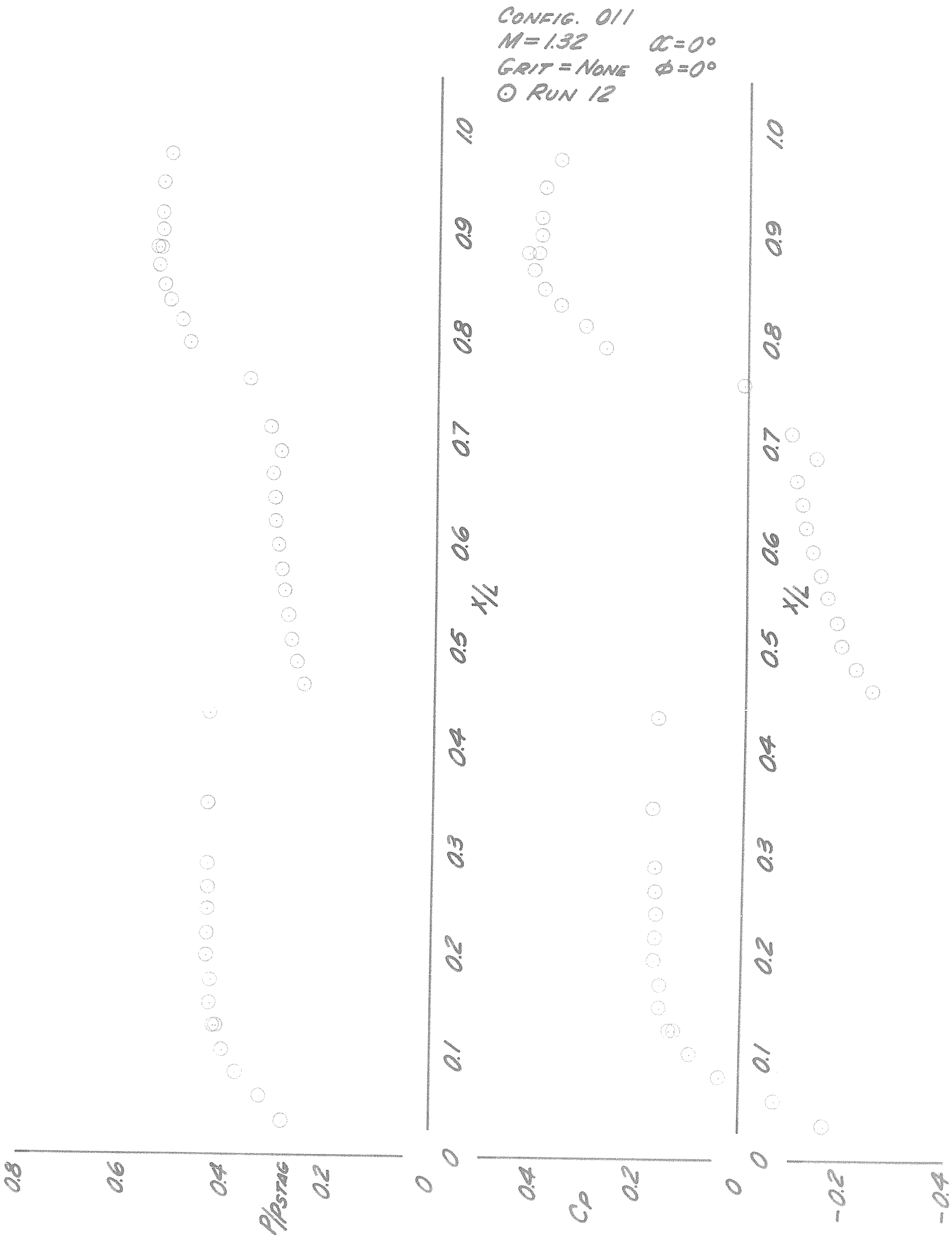

CONFIG. III
M=3.98 α=0°
GRIT #36 φ=0°
⊙ RUN 4
X/L
P/PSTAG
CP
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
0 0.2 0.4 0.6 0.8
0 0.2 0.4
0 -0.2 -0.4

PLOT 4

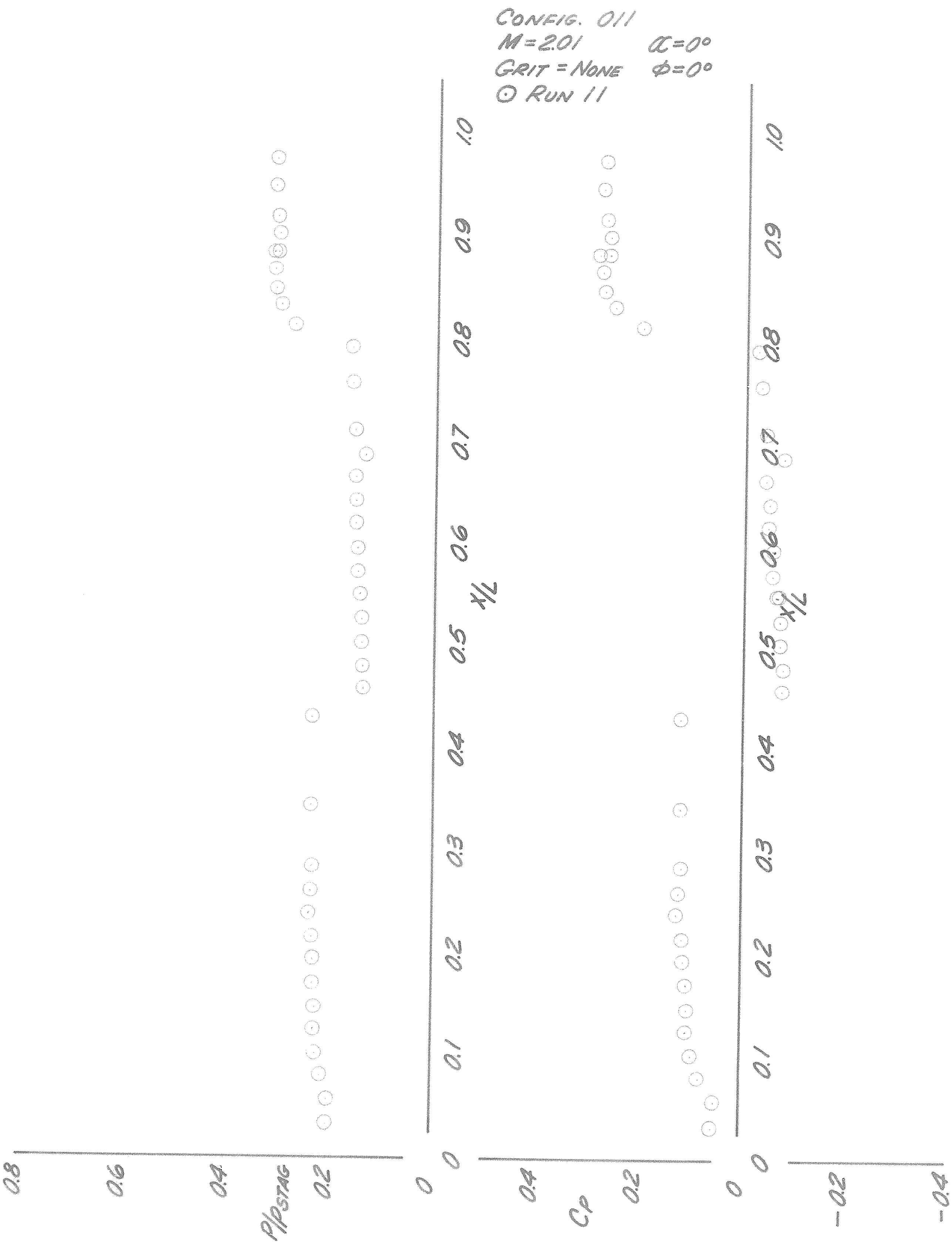
SWT 20-308



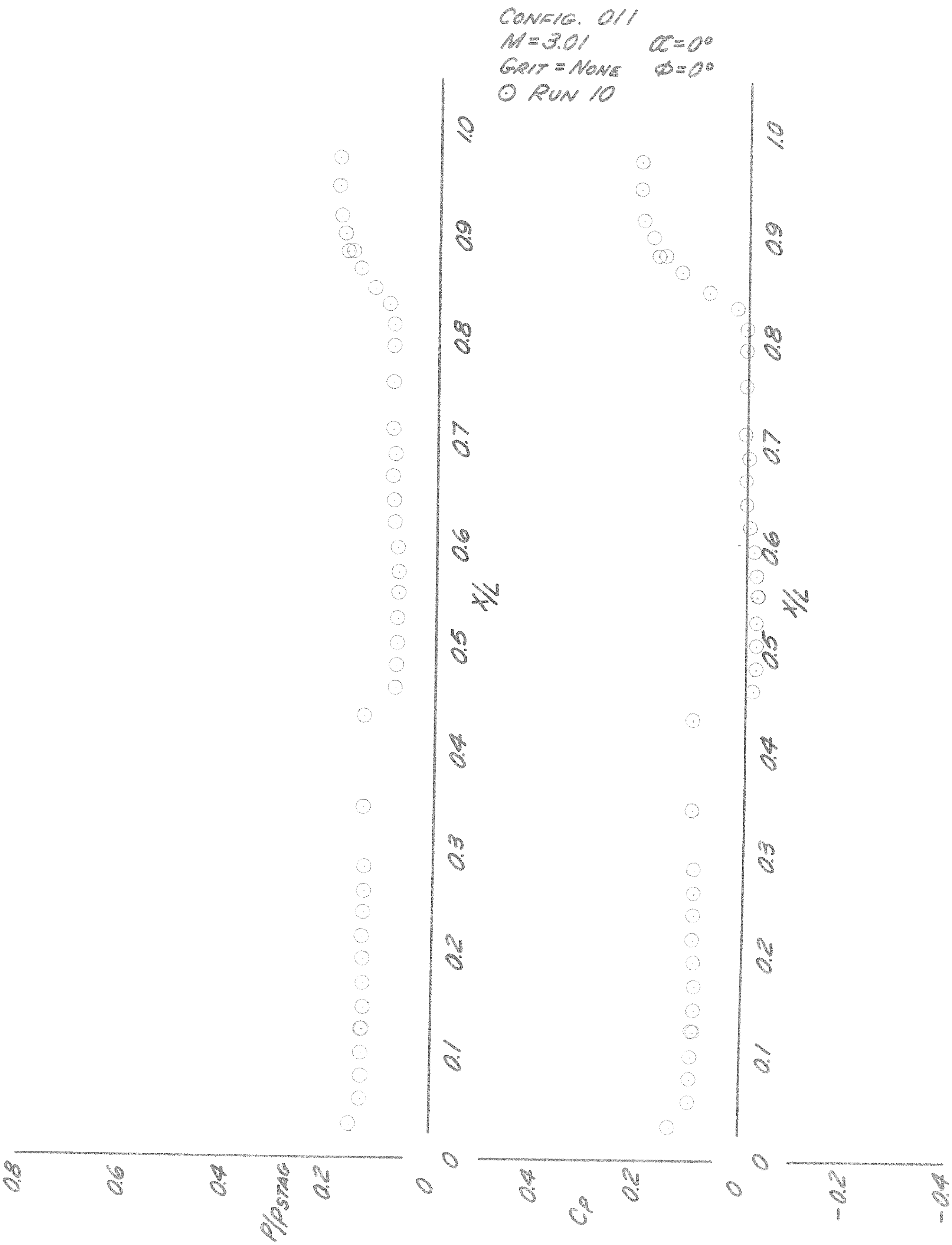
PLOT 5


CONFIG. 011
M = 1.32 α = 0°
GRIT = NONE φ = 0°
⊙ RUN 12
X/L
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
P/PSTAG
0.8 0.6 0.4 0.2 0
CP
0.4 0.2 0 −0.2 −0.4

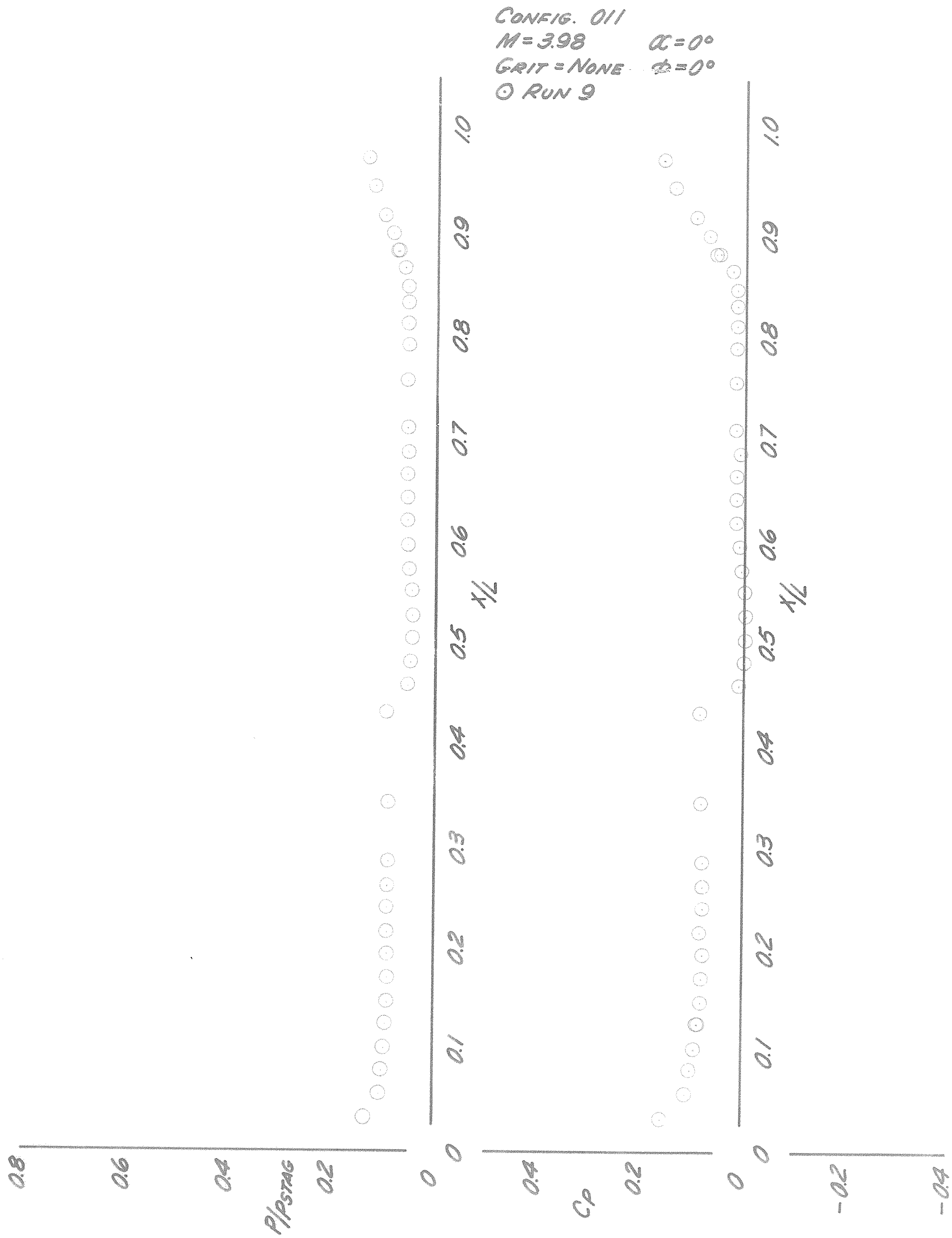
SWT 20-308



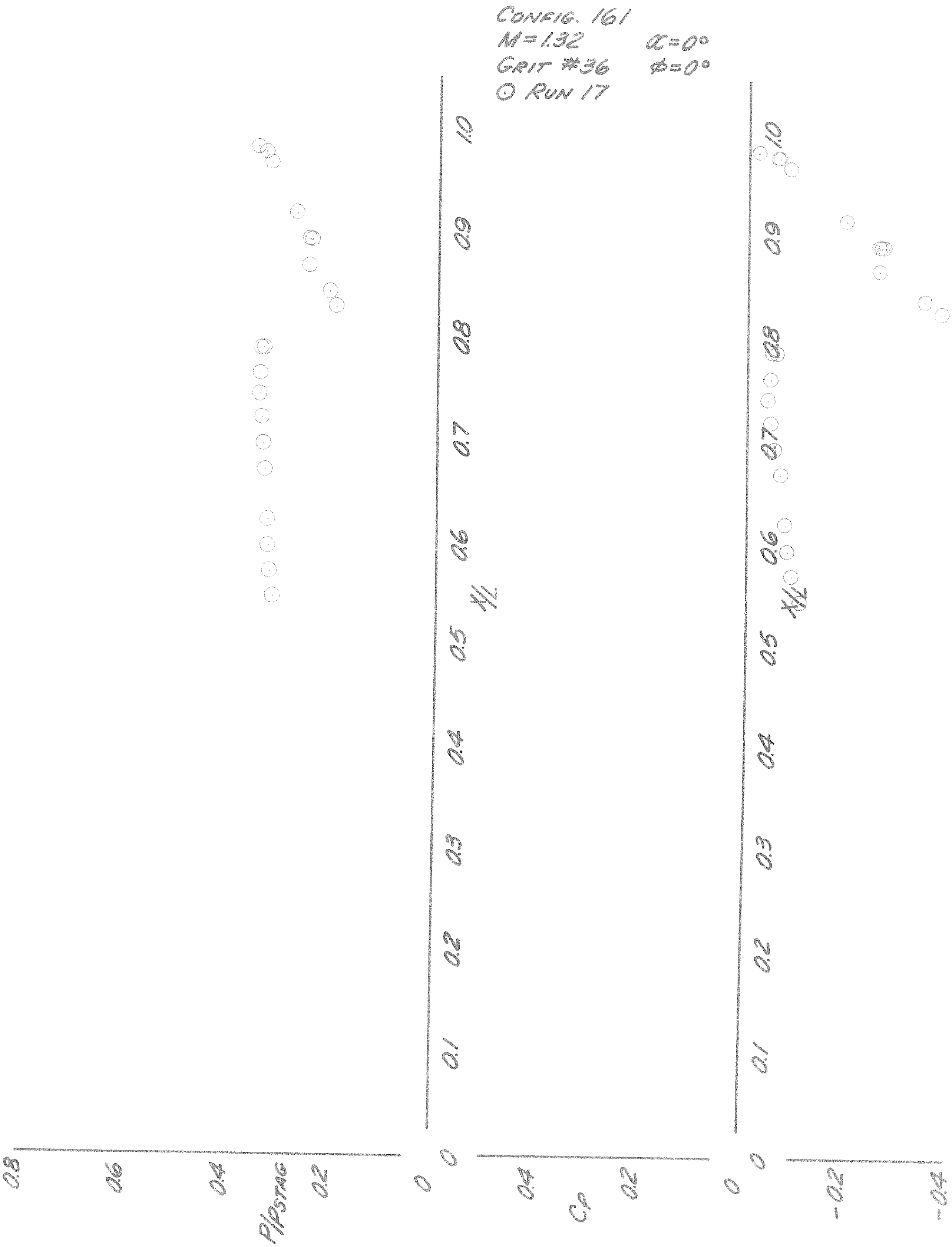
PLOT 7



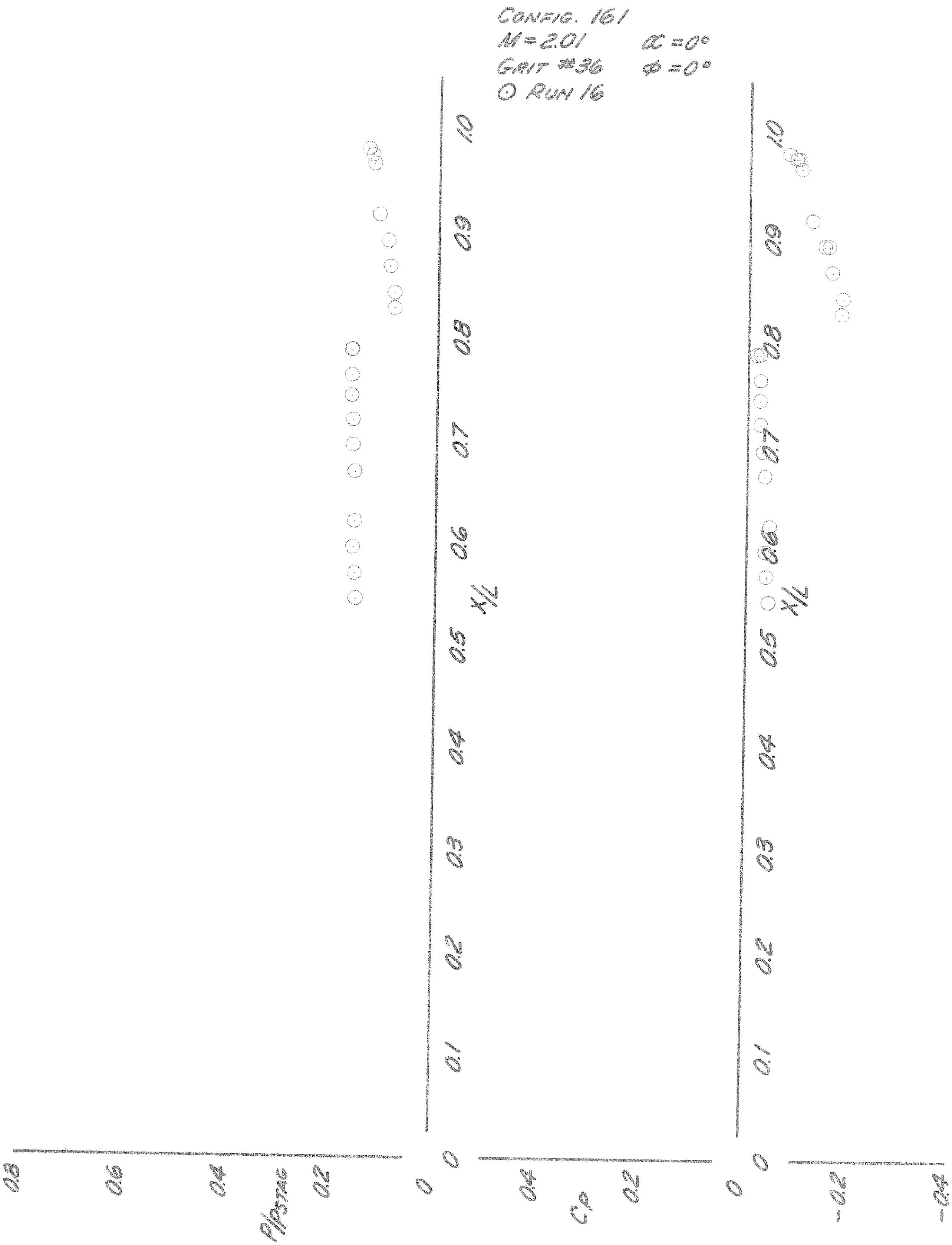
PLOT 8



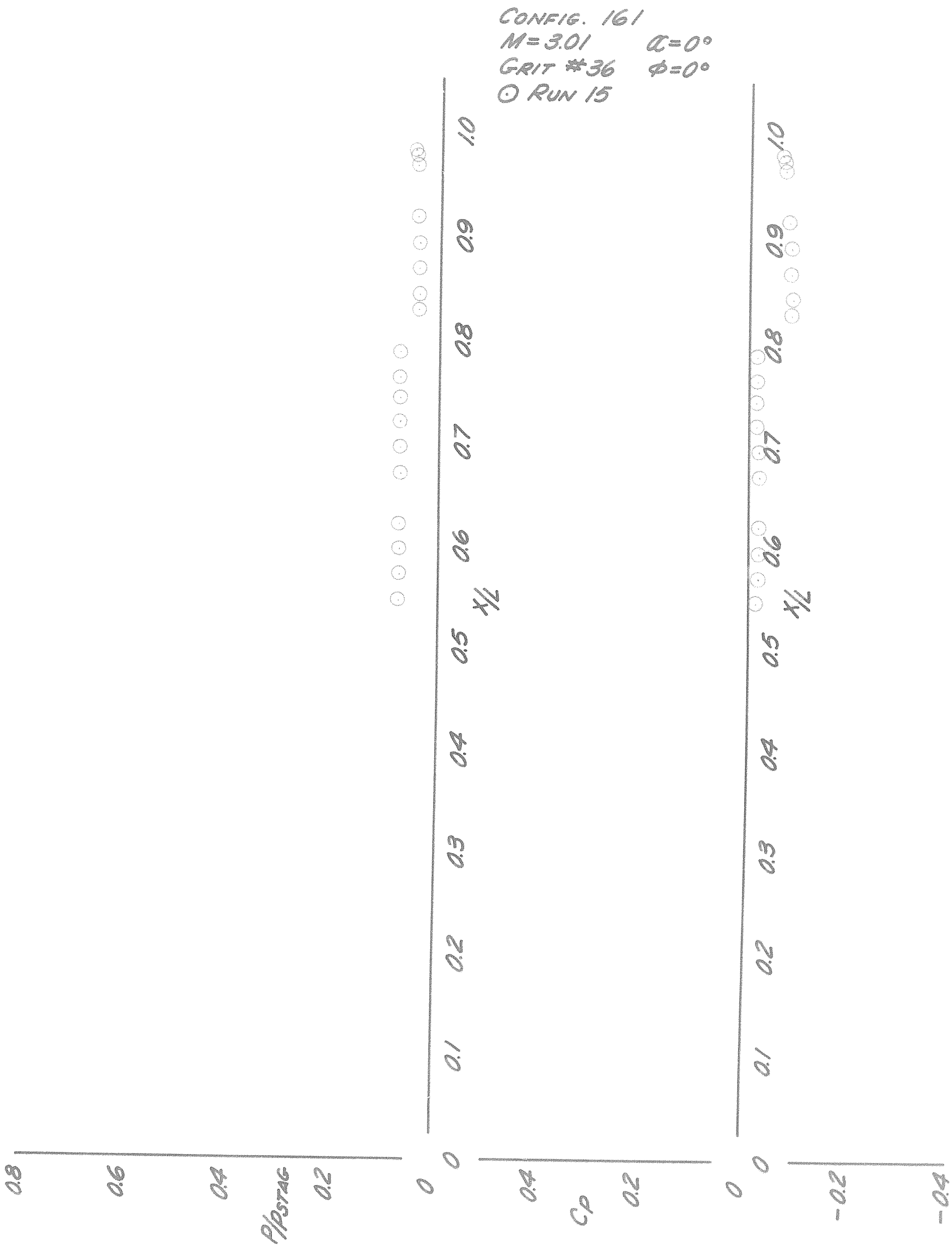
PLOT 9


CONFIG. 161
M=1.32 α=0°
GRIT #36 φ=0°
⊙ RUN 17
x/L
P/PSTAG
CP
-0.2
-0.4
0.2
0.4
0.6
0.8
0.1
0.3
0.5
0.7
0.9
1.0
0

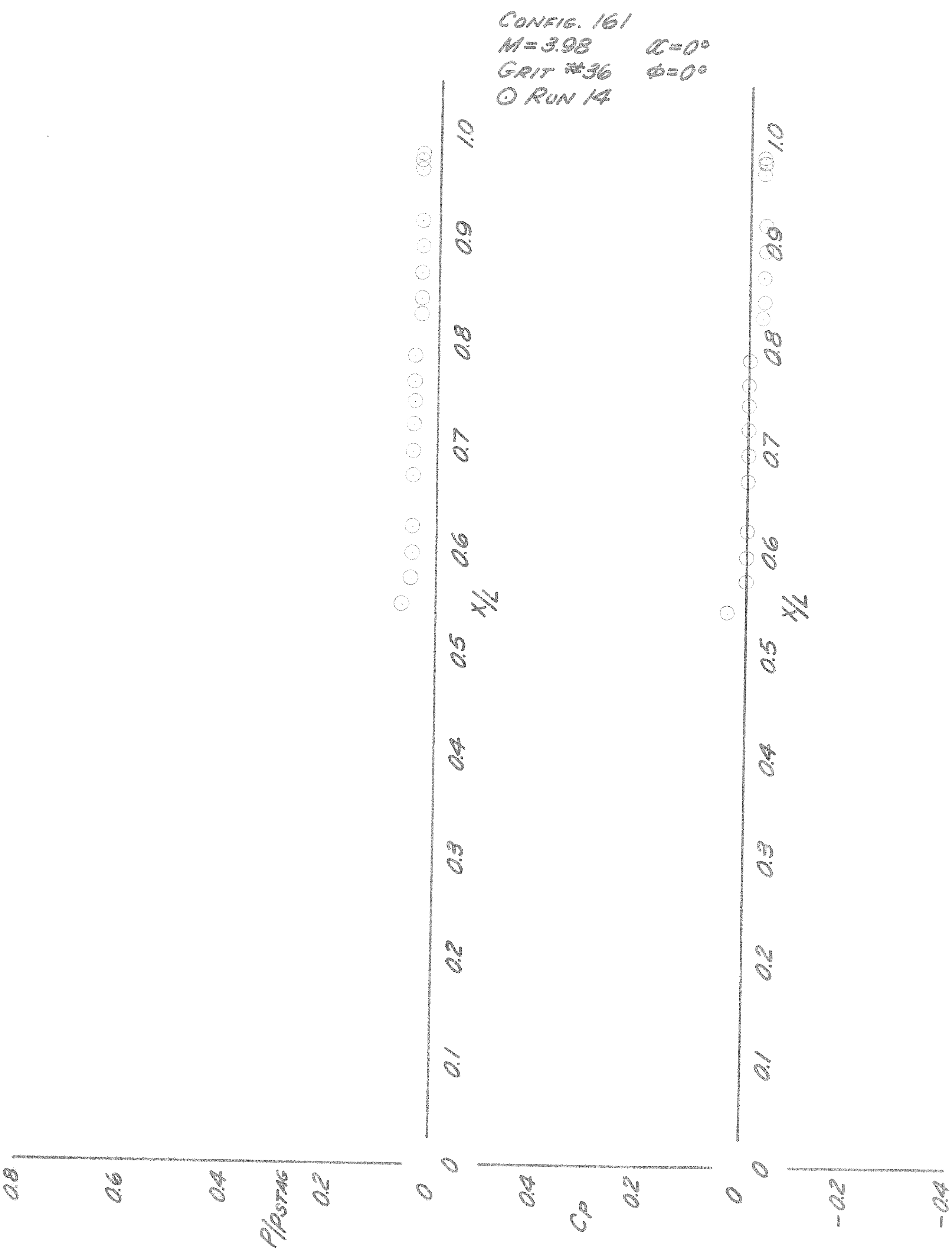
PLOT 10

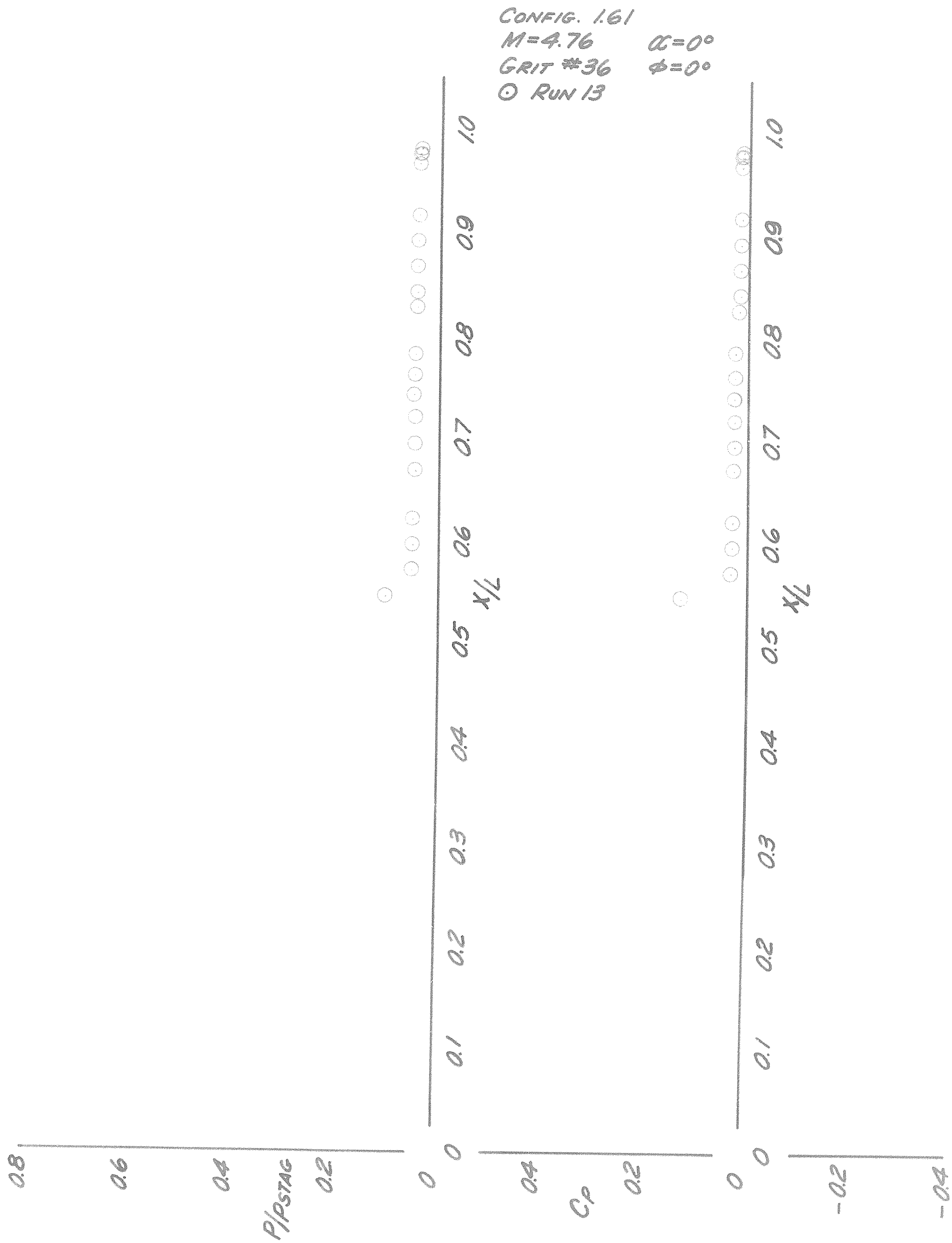

CONFIG. 161
M = 2.01   α = 0°
GRIT #36   φ = 0°
⊙ RUN 16
X/L
P/PSTAG
CP
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

PLOT 11


CONFIG. 161
M=3.01 α=0°
GRIT #36 φ=0°
⊙ RUN 15
X/L
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
P/PSTAG
0.8 0.6 0.4 0.2 0
CP
0.4 0.2 0 -0.2 -0.4

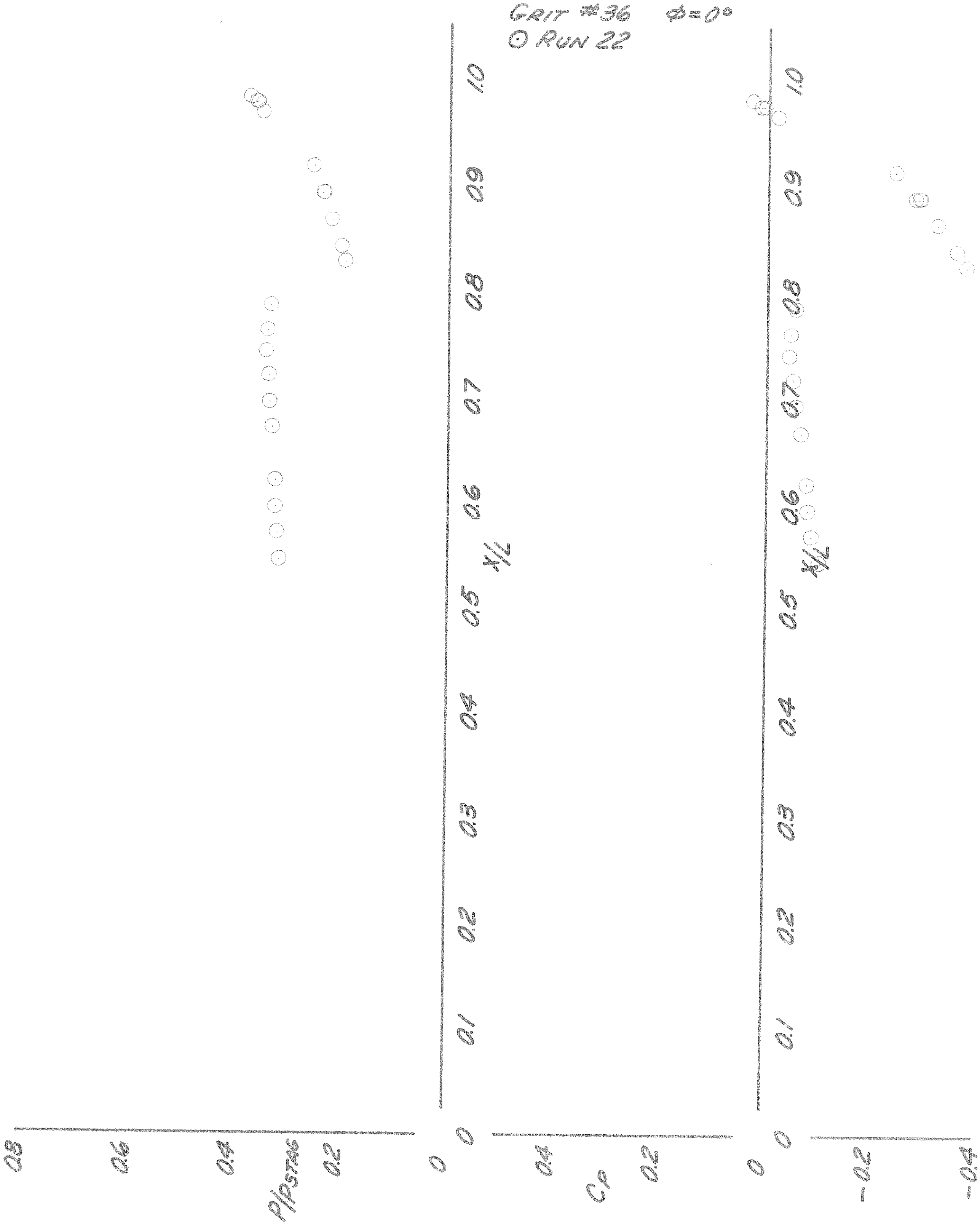
PLOT 12


CONFIG. 161
M=3.98 α=0°
GRIT #36 φ=0°
⊙ RUN 14
X/L
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.8
0.6
0.4
P/PSTAG
0.2
0
0.4
CP
0.2
0
-0.2
-0.4



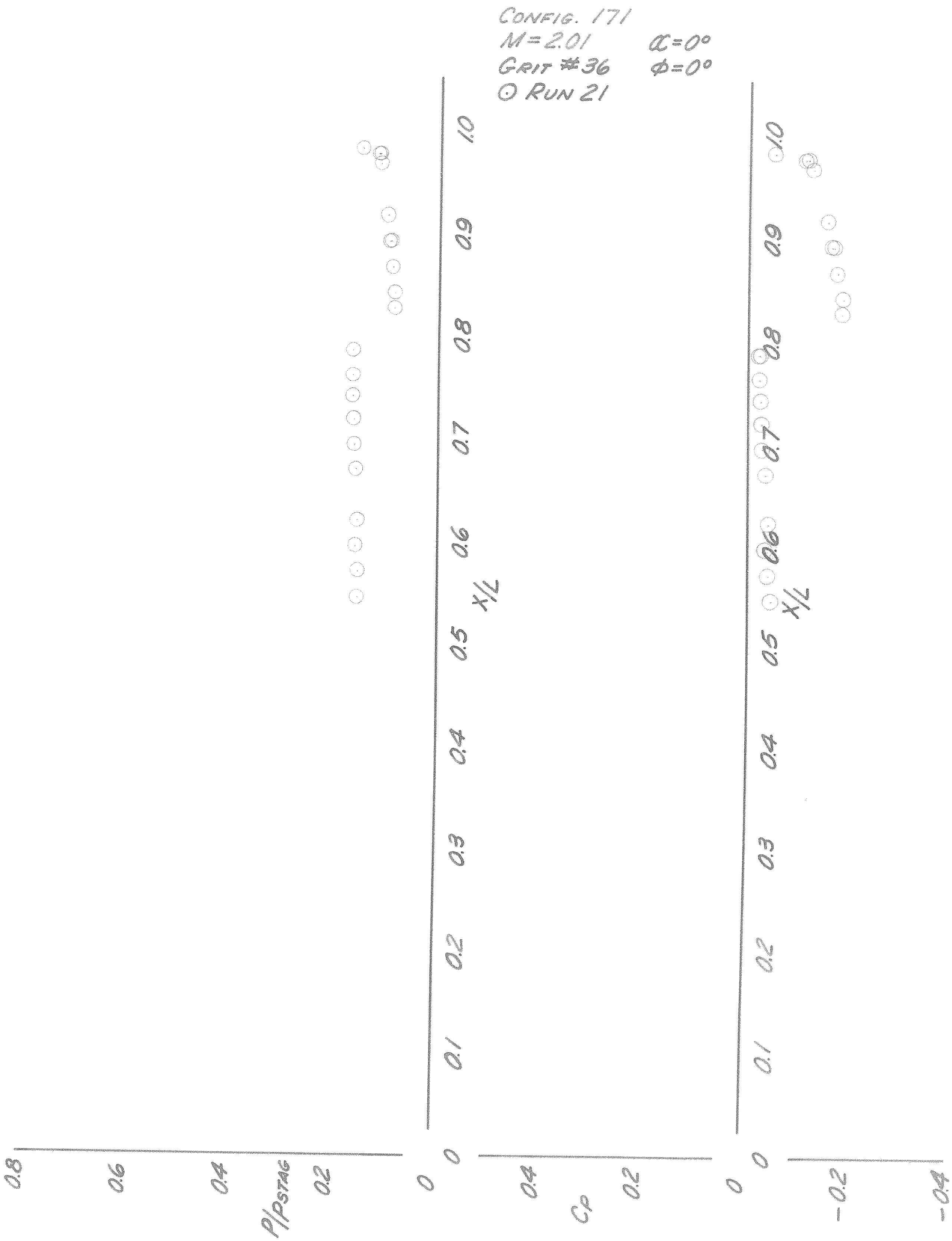
PLOT 14

CONFIG. 171
M = 1.32 $\quad \alpha = 0°$
GRIT #36 $\quad \phi = 0°$
⊙ RUN 22



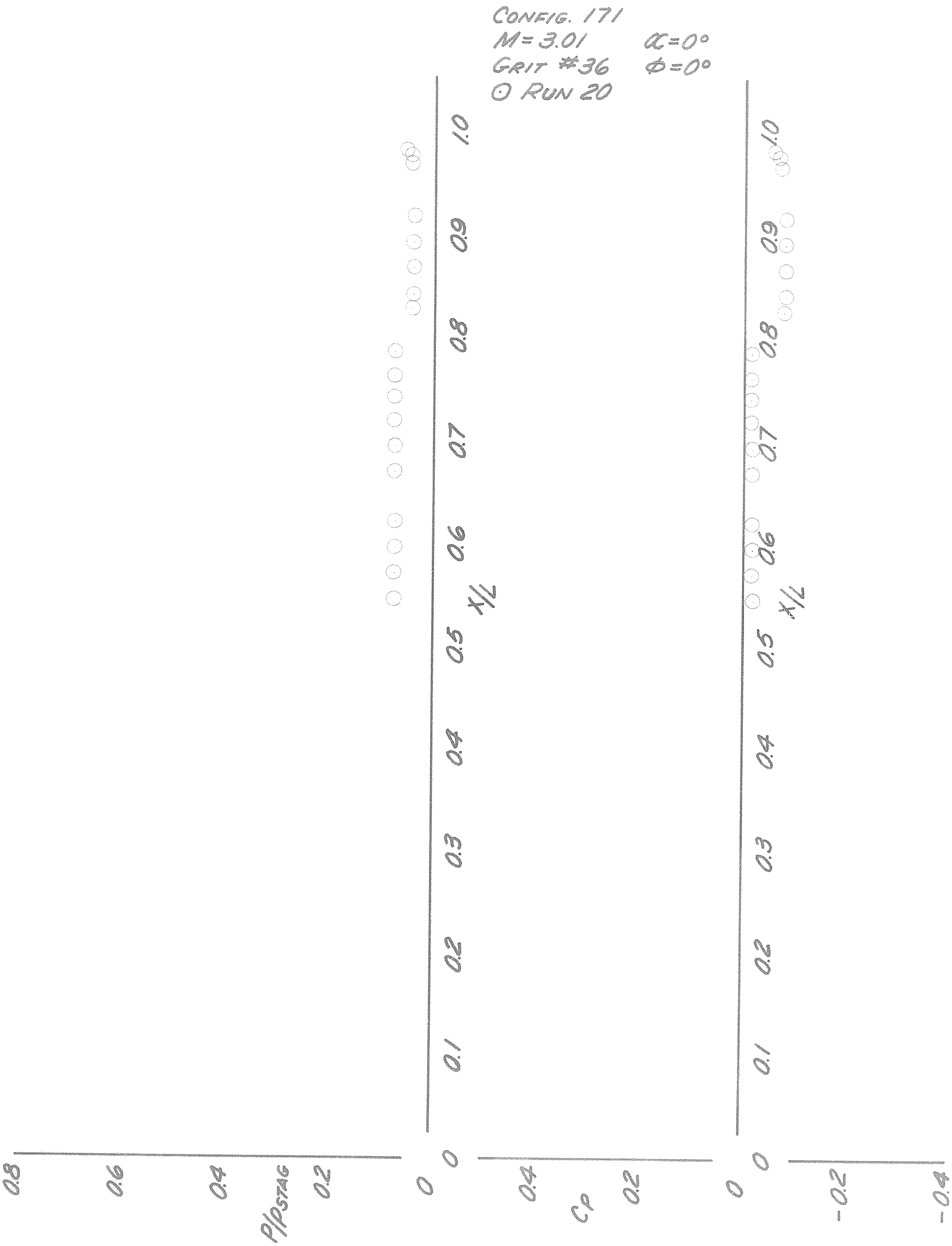
PLOT 15

SWT 20-308



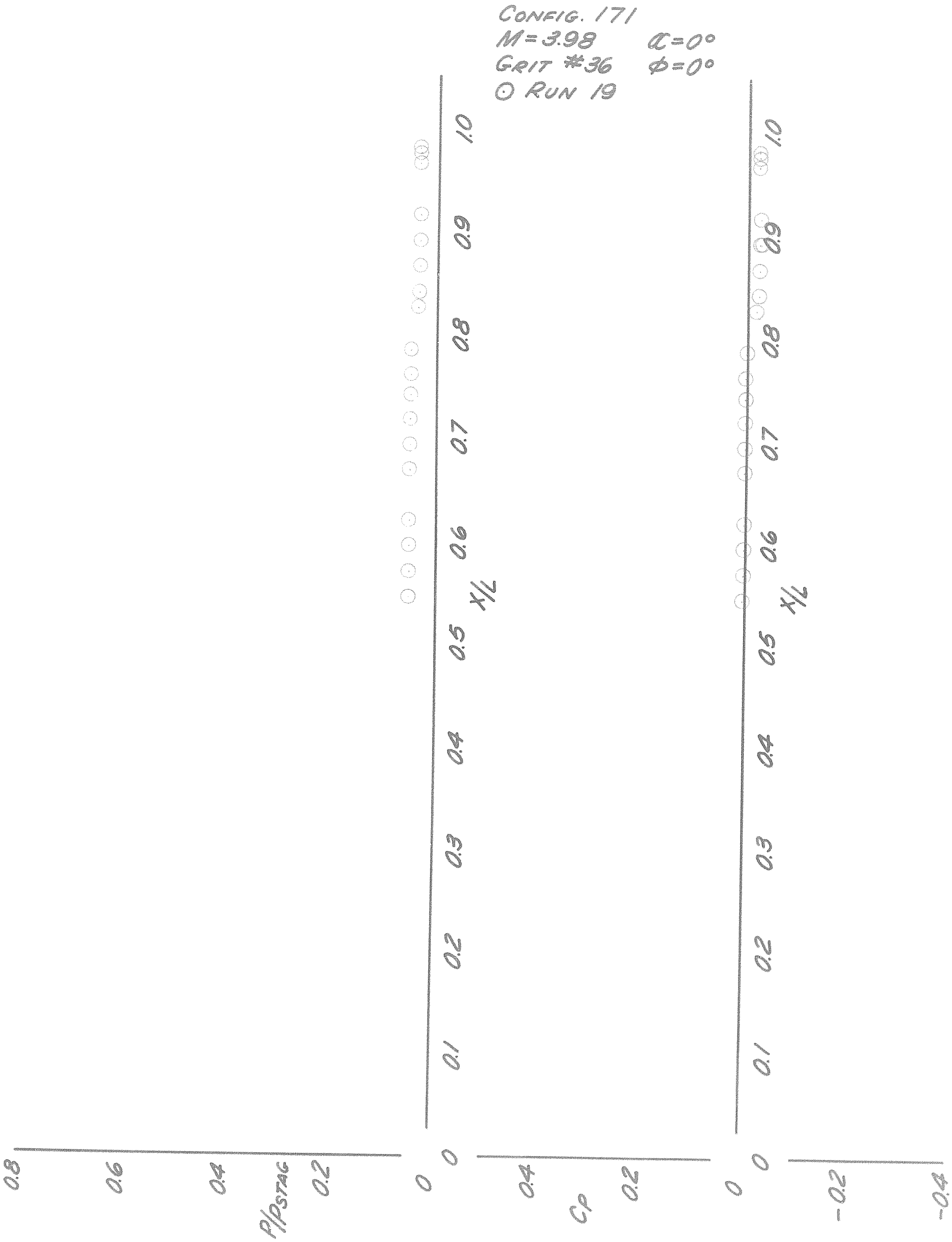
PLOT 16

SWT 20-308

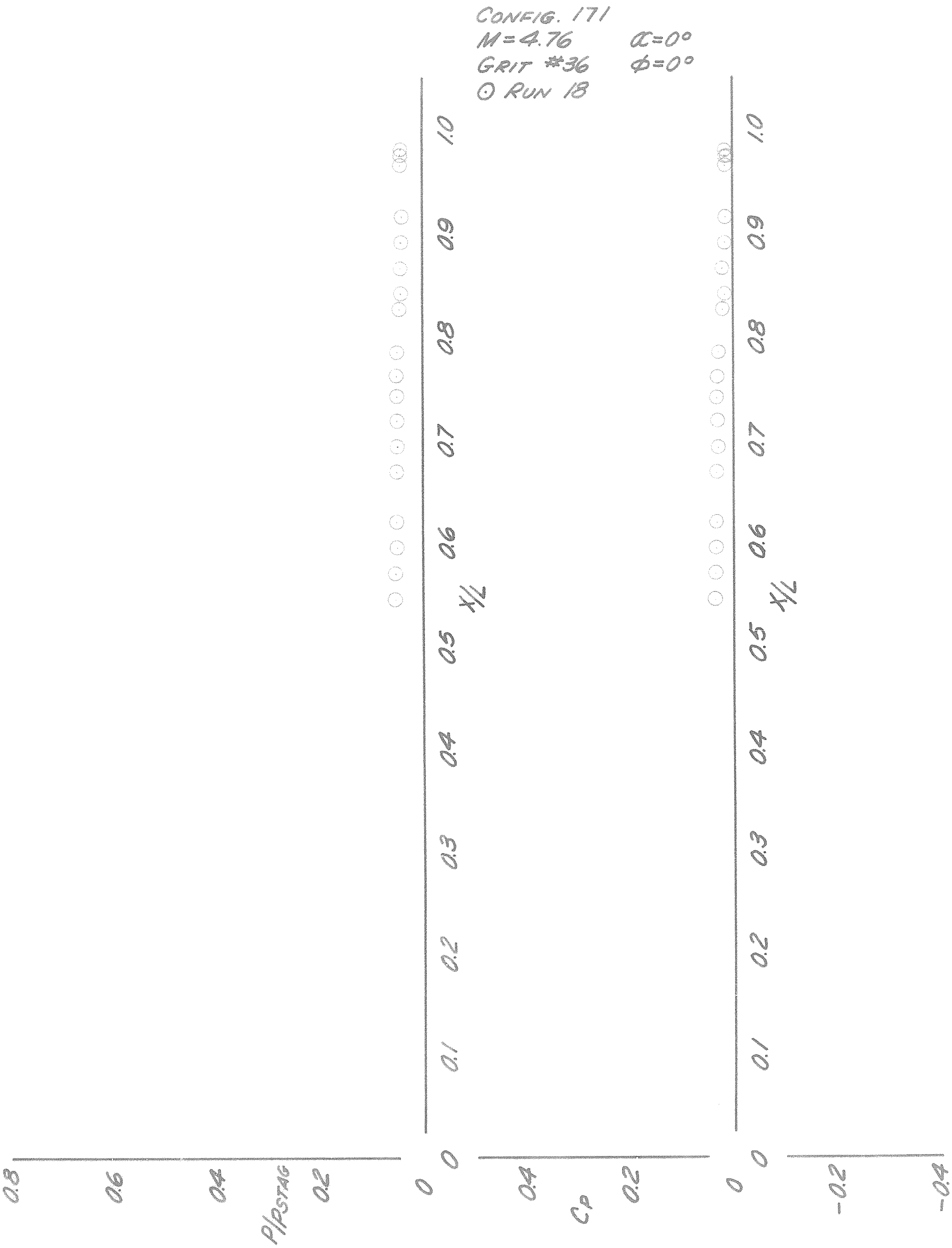


PLOT 17

SWT 20-308

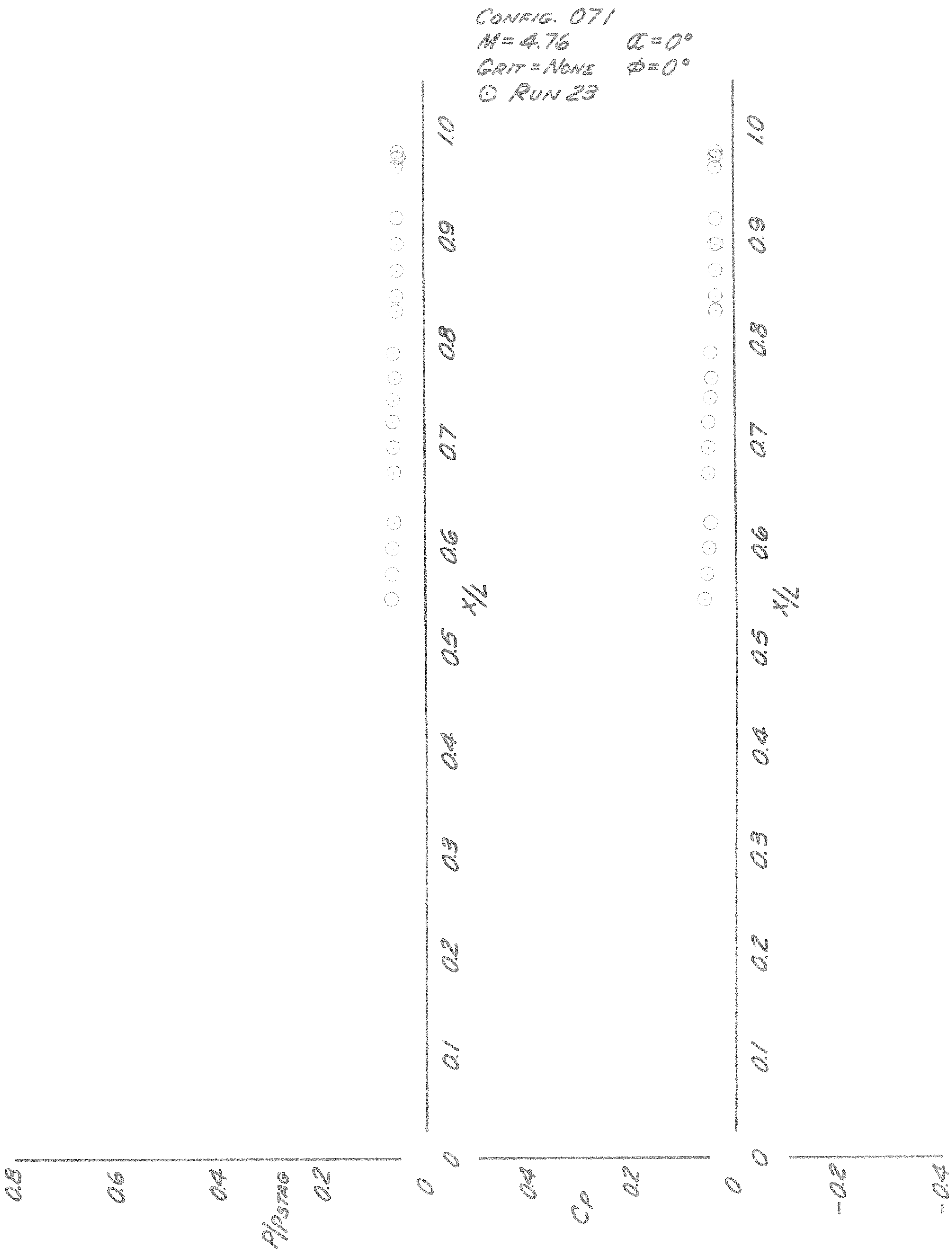


PLOT 18


CONFIG. 171
M=4.76
α=0°
GRIT #36
φ=0°
⊙ RUN 18
X/L
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
P/PSTAG
0 0.2 0.4 0.6 0.8
CP
0 0.2 0.4 -0.2 -0.4

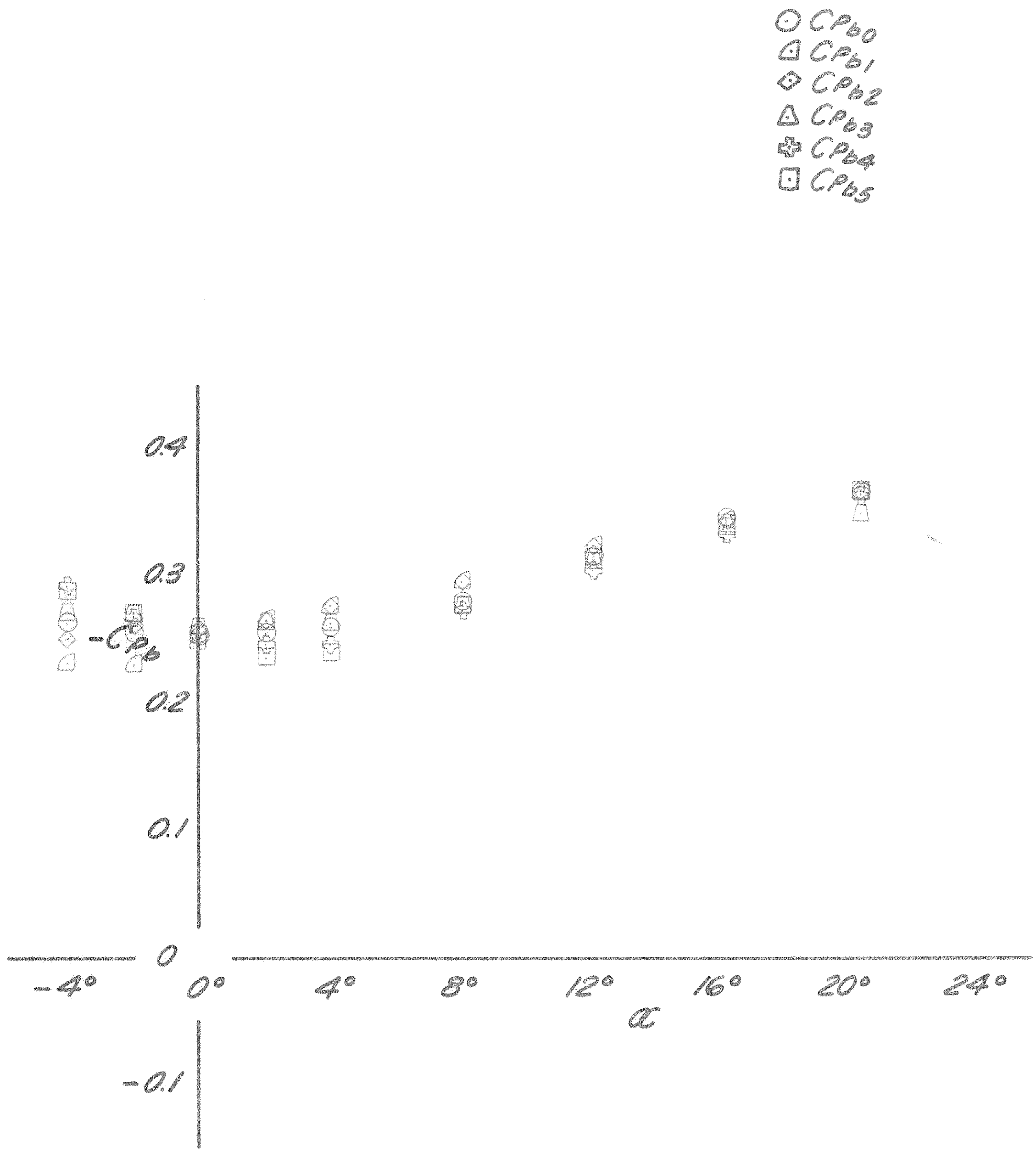
PLOT 19

SWT 20-308

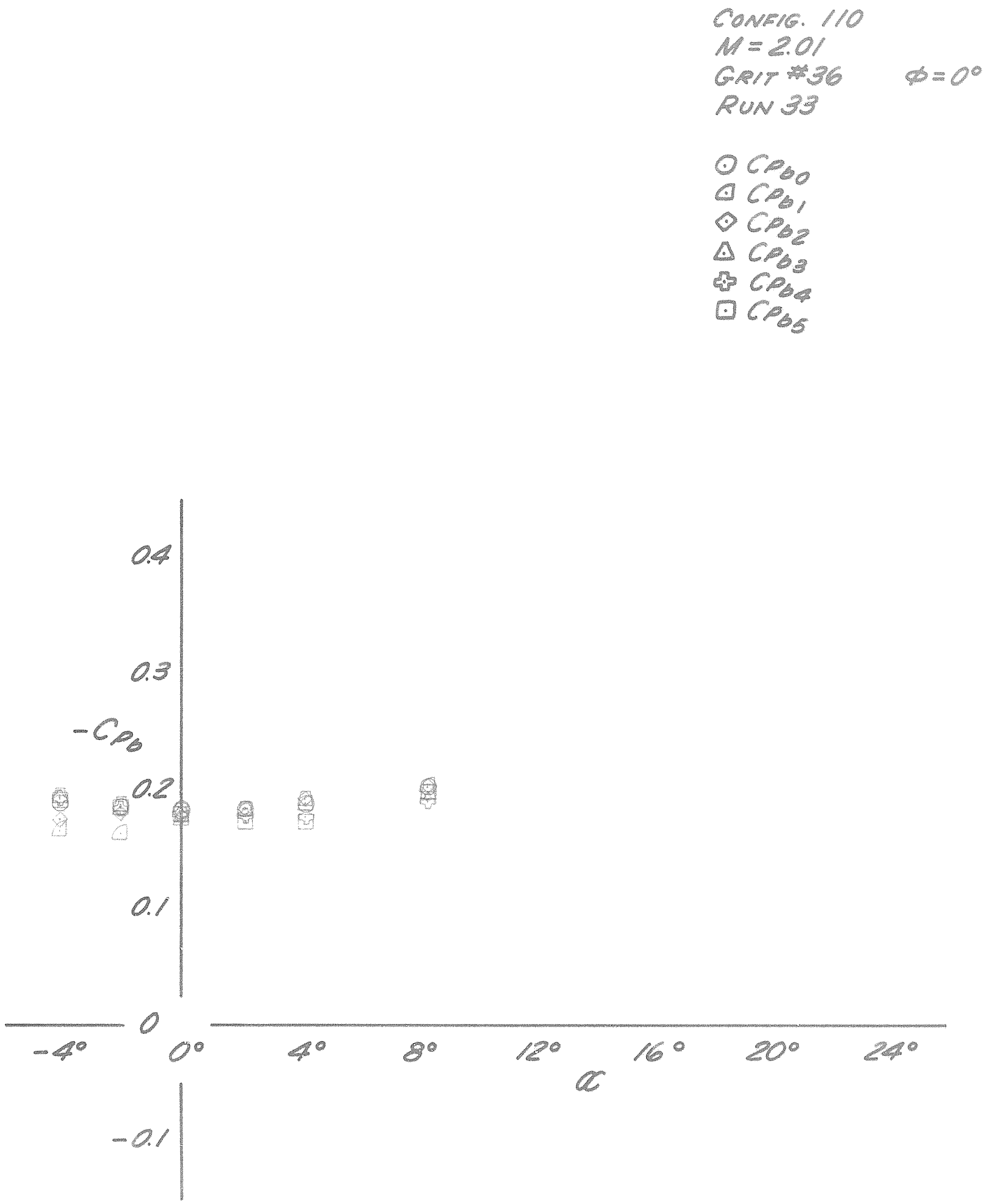


PLOT 20

CONFIG. 110
M=1.32
GRIT #36 Φ=0°
RUN 36



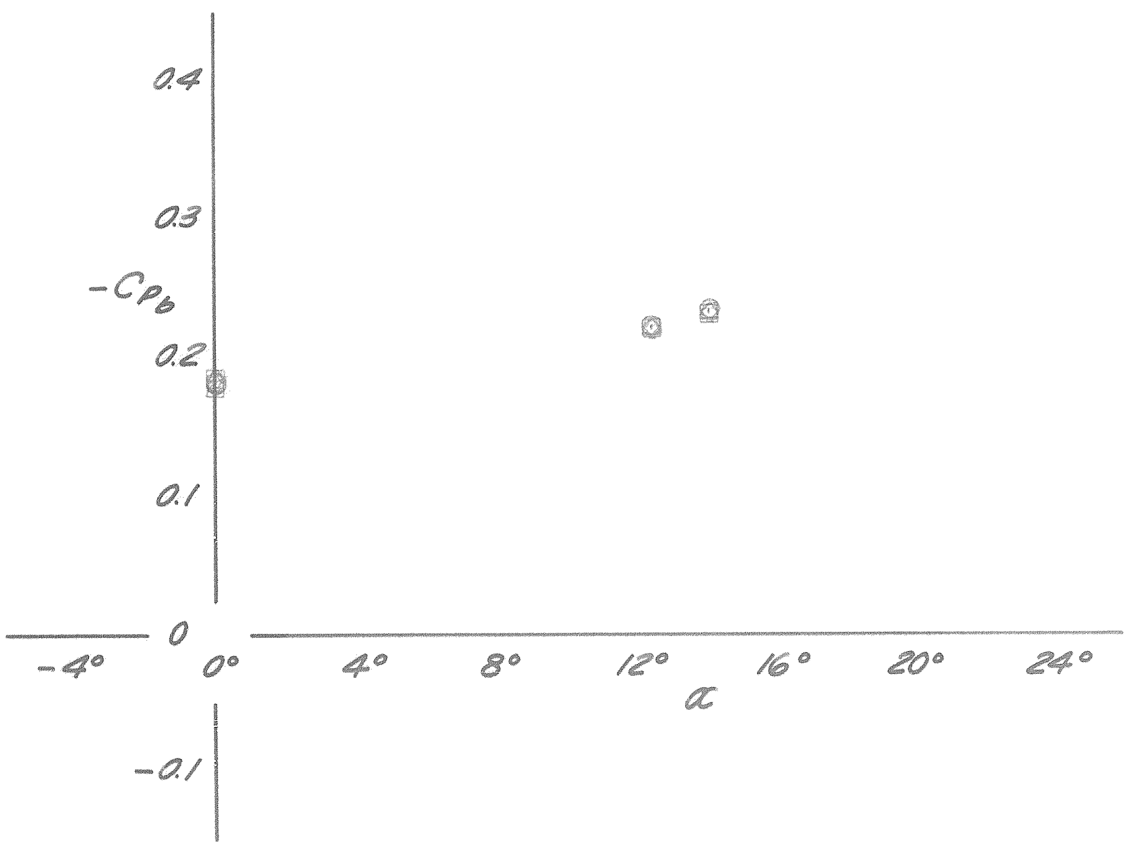
SWT 20-308


CONFIG. 110
M = 2.01
GRIT #36
φ = 0°
RUN 33
CPb0
CPb1
CPb2
CPb3
CPb4
CPb5
0.4
0.3
-CPb
0.2
0.1
0
-0.1
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

CONFIG. 110
M = 2.01
GRIT #36 $\phi = 0°$
RUN 34

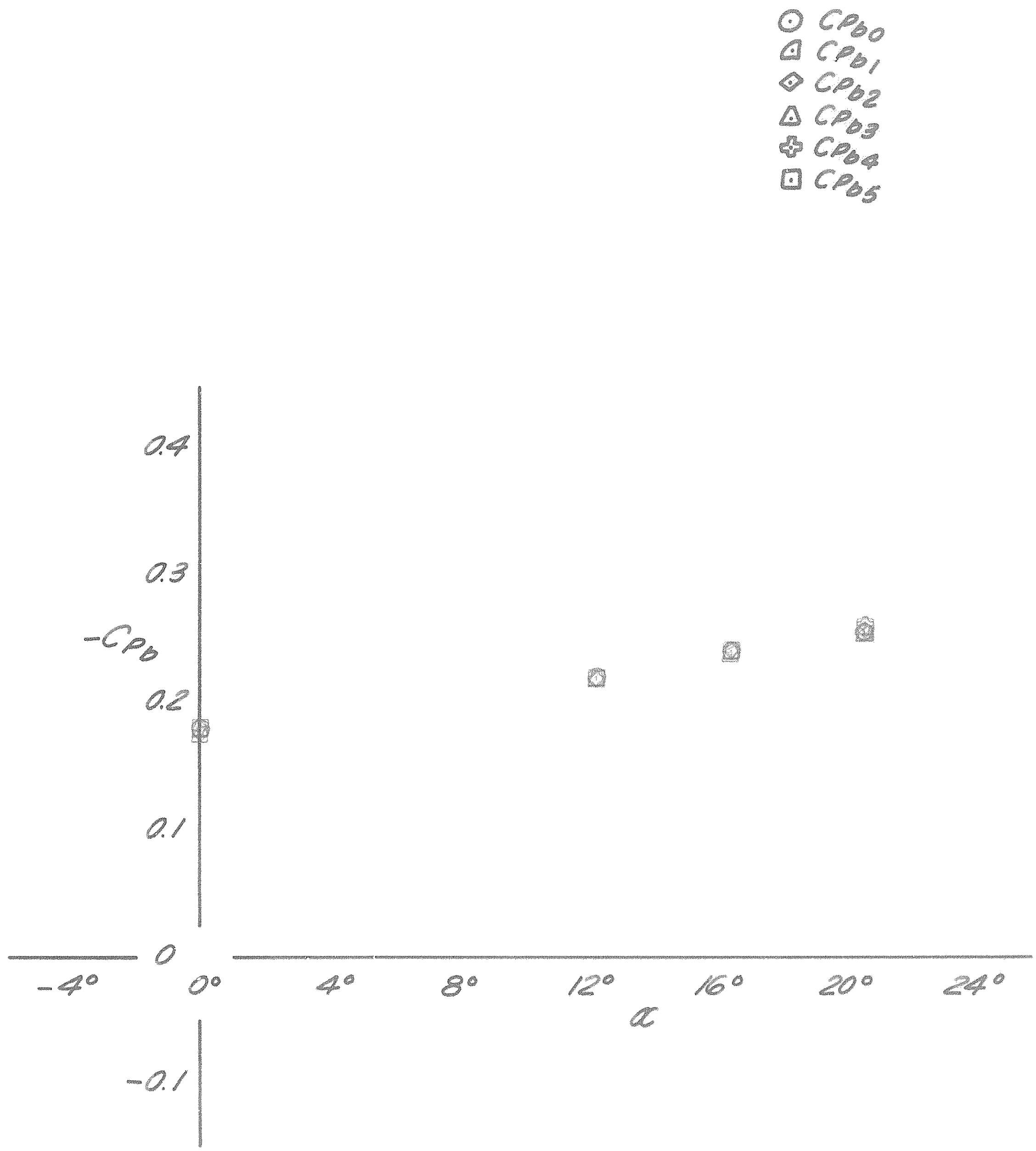
⊙ $C_{P_{b0}}$
$C_{P_{b1}}$
◇ $C_{P_{b2}}$
△ $C_{P_{b3}}$
$C_{P_{b4}}$
□ $C_{P_{b5}}$



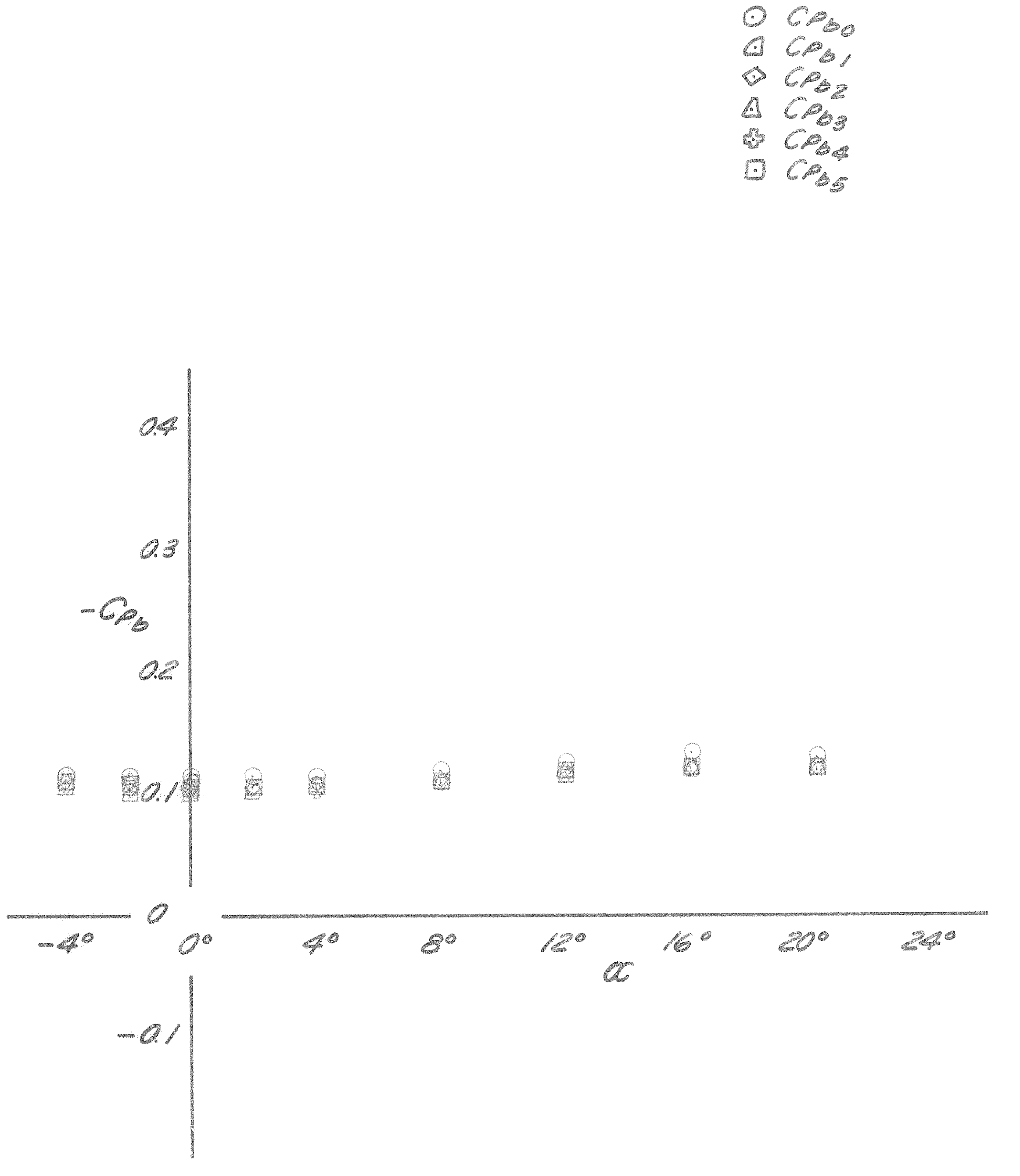
PLOT 23

SWT 20-308

CONFIG. 110
M=2.01
GRIT #36 $\phi=0°$
RUN 35, REDUCED P_t



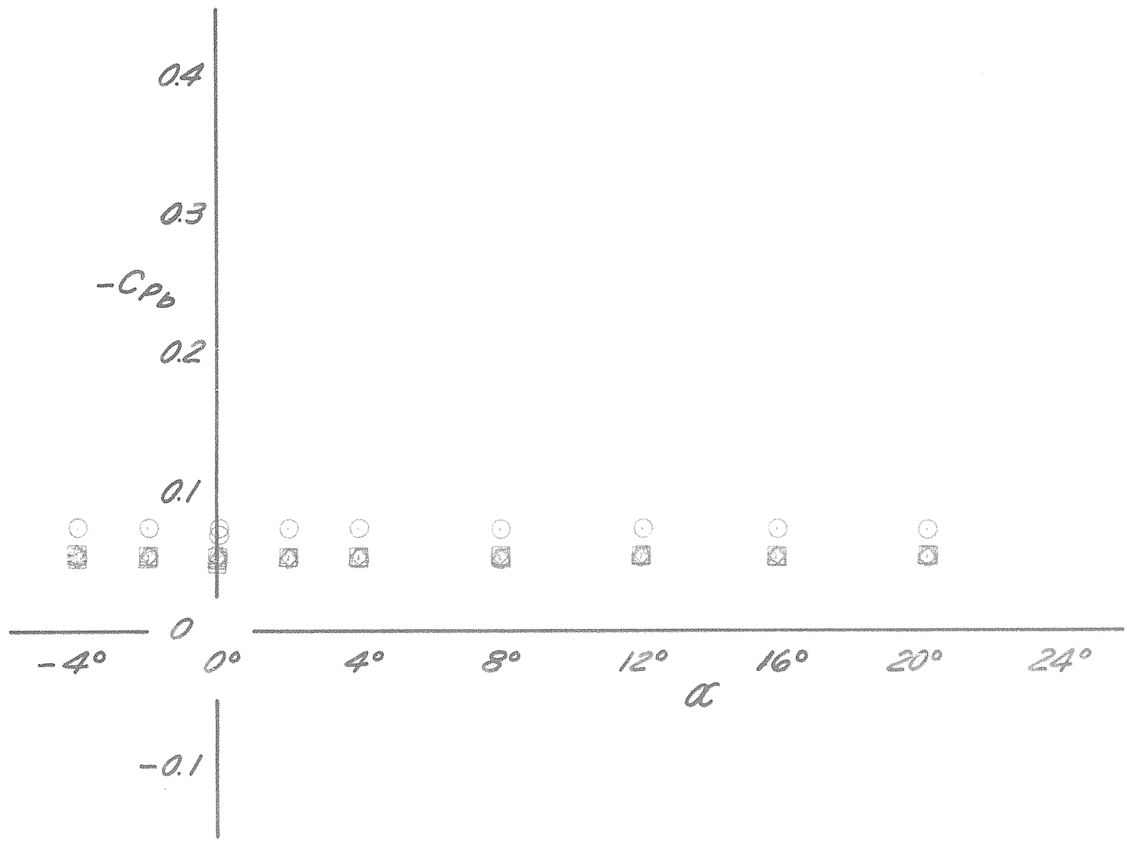
CONFIG. 110
M = 3.01
GRIT #36 $\phi = 0°$
RUN 32



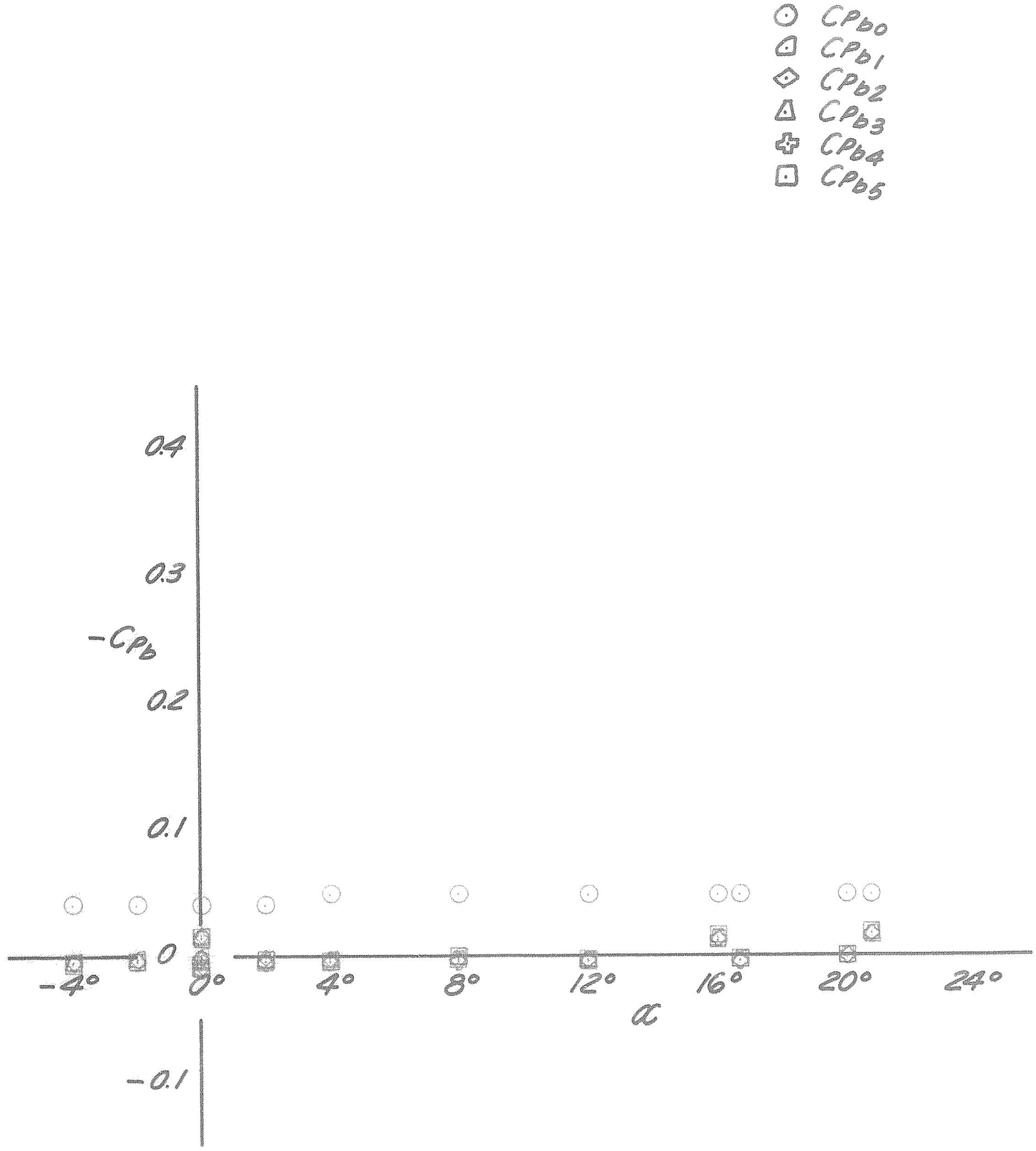
SWT 20-308

CONFIG. 110
M=3.98
GRIT #36 $\phi = 0°$
RUN 31

⊙ $C_{P_{b0}}$
$C_{P_{b1}}$
◇ $C_{P_{b2}}$
△ $C_{P_{b3}}$
$C_{P_{b4}}$
□ $C_{P_{b5}}$

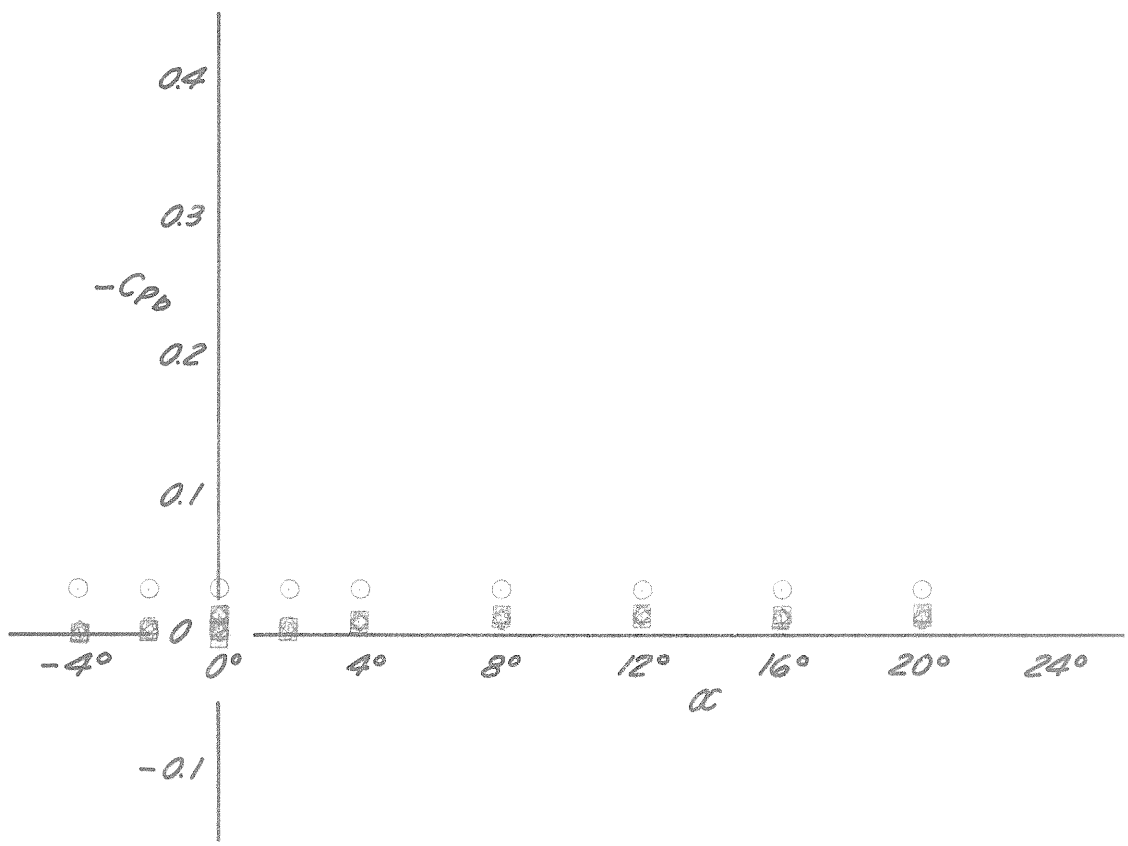


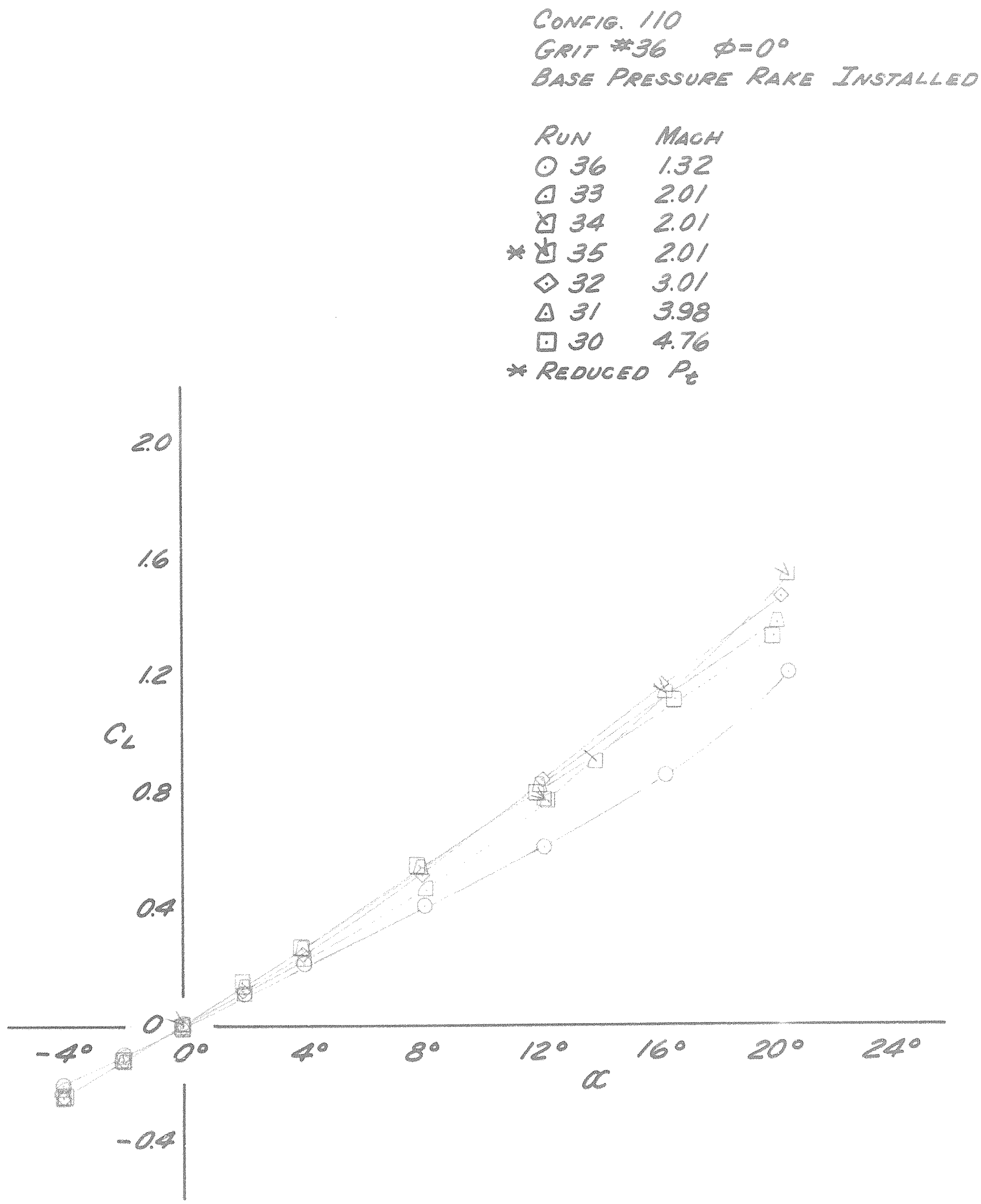
CONFIG. 110
M=4.76
GRIT #36 $\phi=0°$
RUN 30

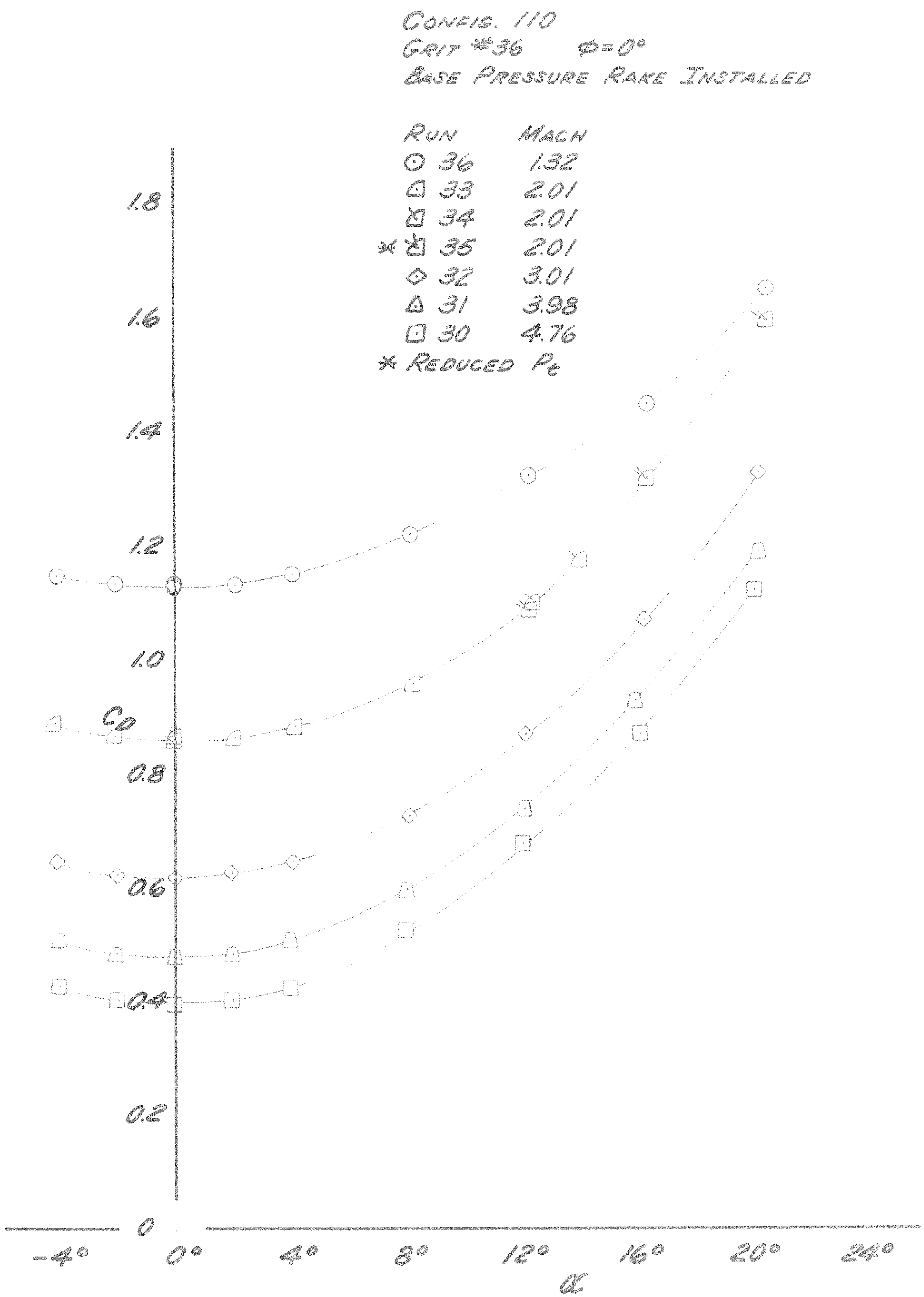


CONFIG. 010
M=4.76
GRIT = NONE   φ=0°
RUN 37

⊙ $C_{P_{b0}}$
◪ $C_{P_{b1}}$
◇ $C_{P_{b2}}$
△ $C_{P_{b3}}$
✣ $C_{P_{b4}}$
⊡ $C_{P_{b5}}$



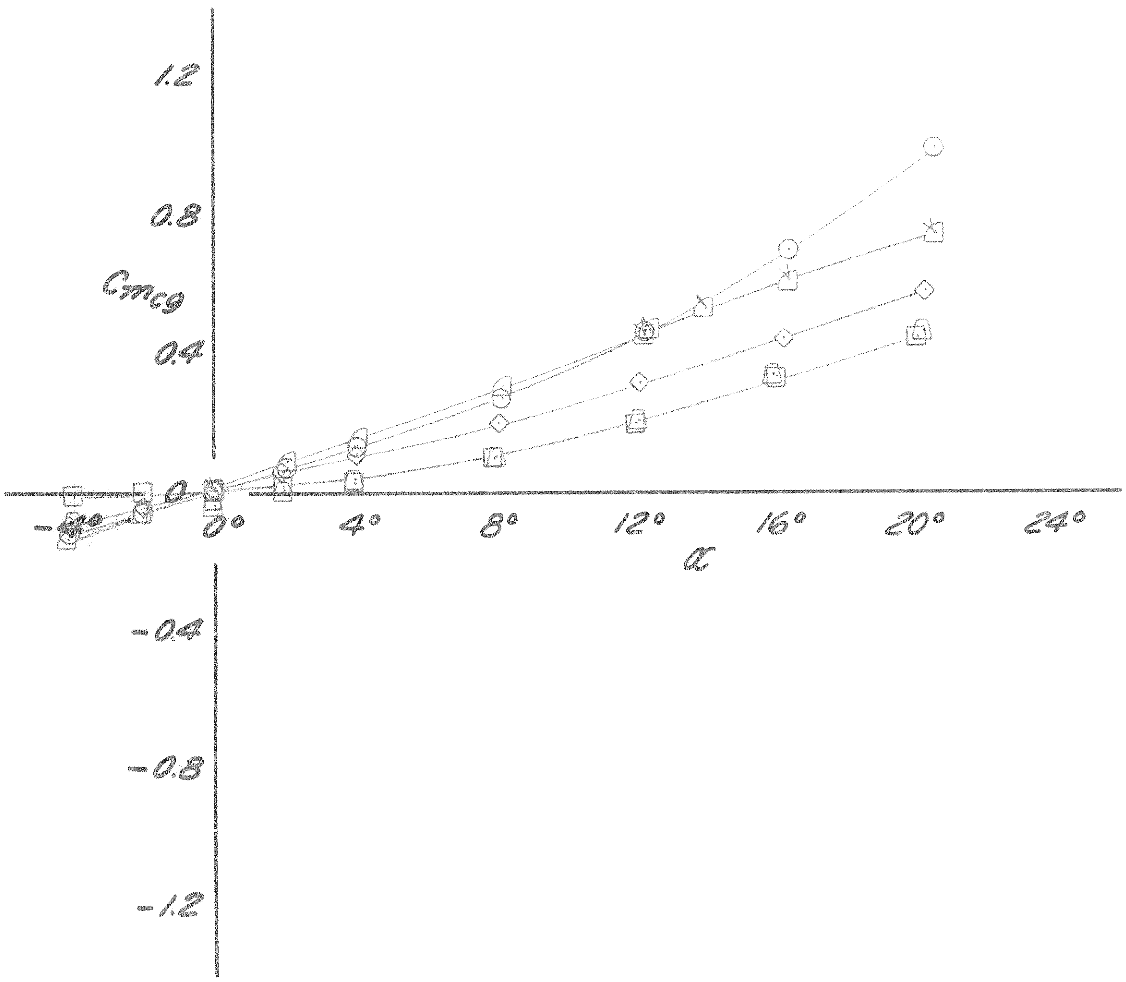

CONFIG. 110
GRIT #36 ϕ=0°
BASE PRESSURE RAKE INSTALLED
RUN MACH
36 1.32
33 2.01
34 2.01
* 35 2.01
32 3.01
31 3.98
30 4.76
* REDUCED P_t
2.0
1.6
1.2
C_L
0.8
0.4
0
-0.4
-4°
0°
4°
8°
12°
16°
20°
24°
α


CONFIG. 110
GRIT #36 Φ=0°
BASE PRESSURE RAKE INSTALLED
RUN MACH
36 1.32
33 2.01
34 2.01
* 35 2.01
32 3.01
31 3.98
30 4.76
* REDUCED P_t
C_D
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

CONFIG. 110
GRIT #36 $\phi = 0°$
BASE PRESSURE RAKE INSTALLED

RUN	MACH
⊙ 36	1.32
33	2.01
34	2.01
* 35	2.01
◇ 32	3.01
△ 31	3.98
⊡ 30	4.76

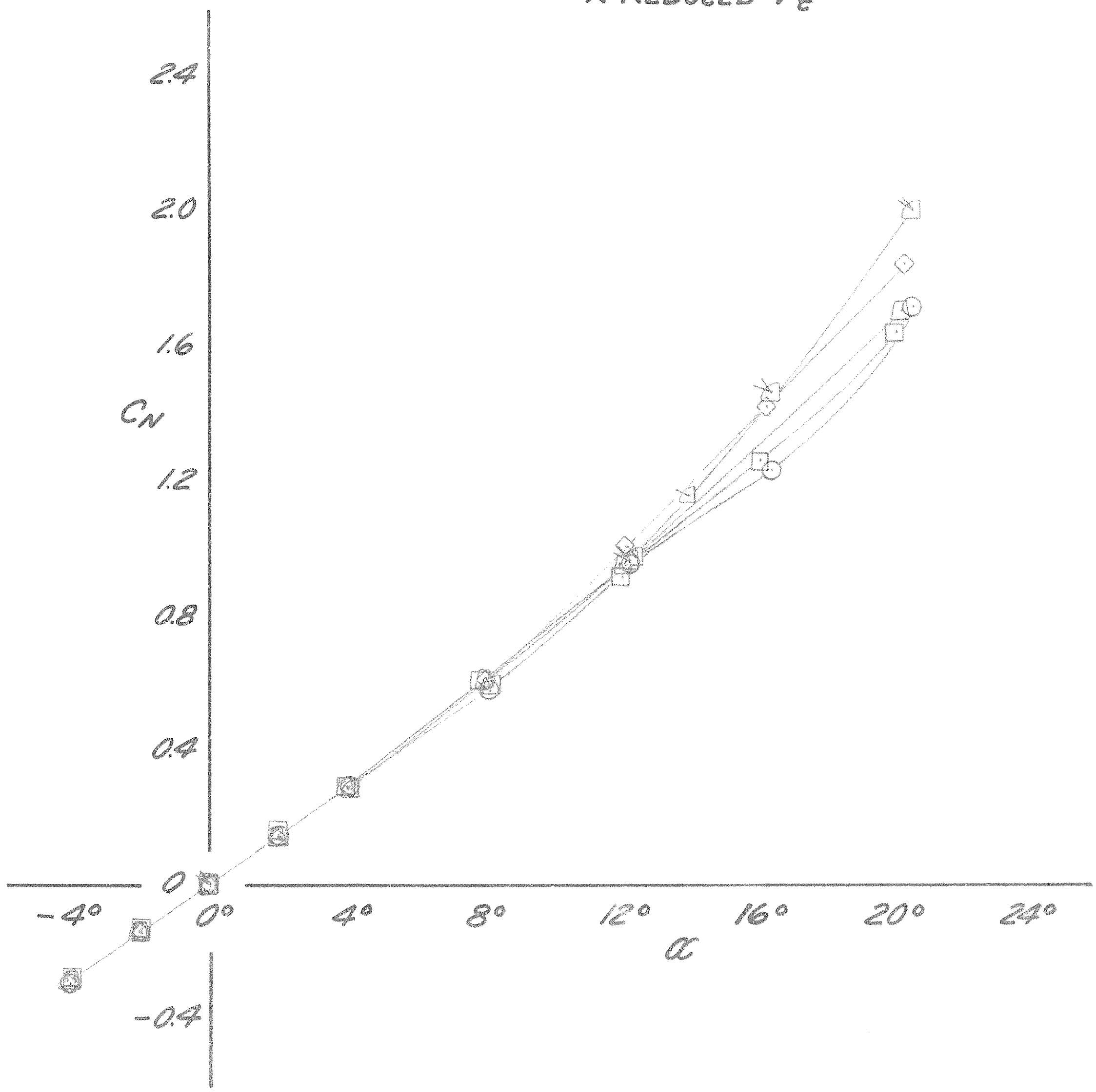
* REDUCED P_t

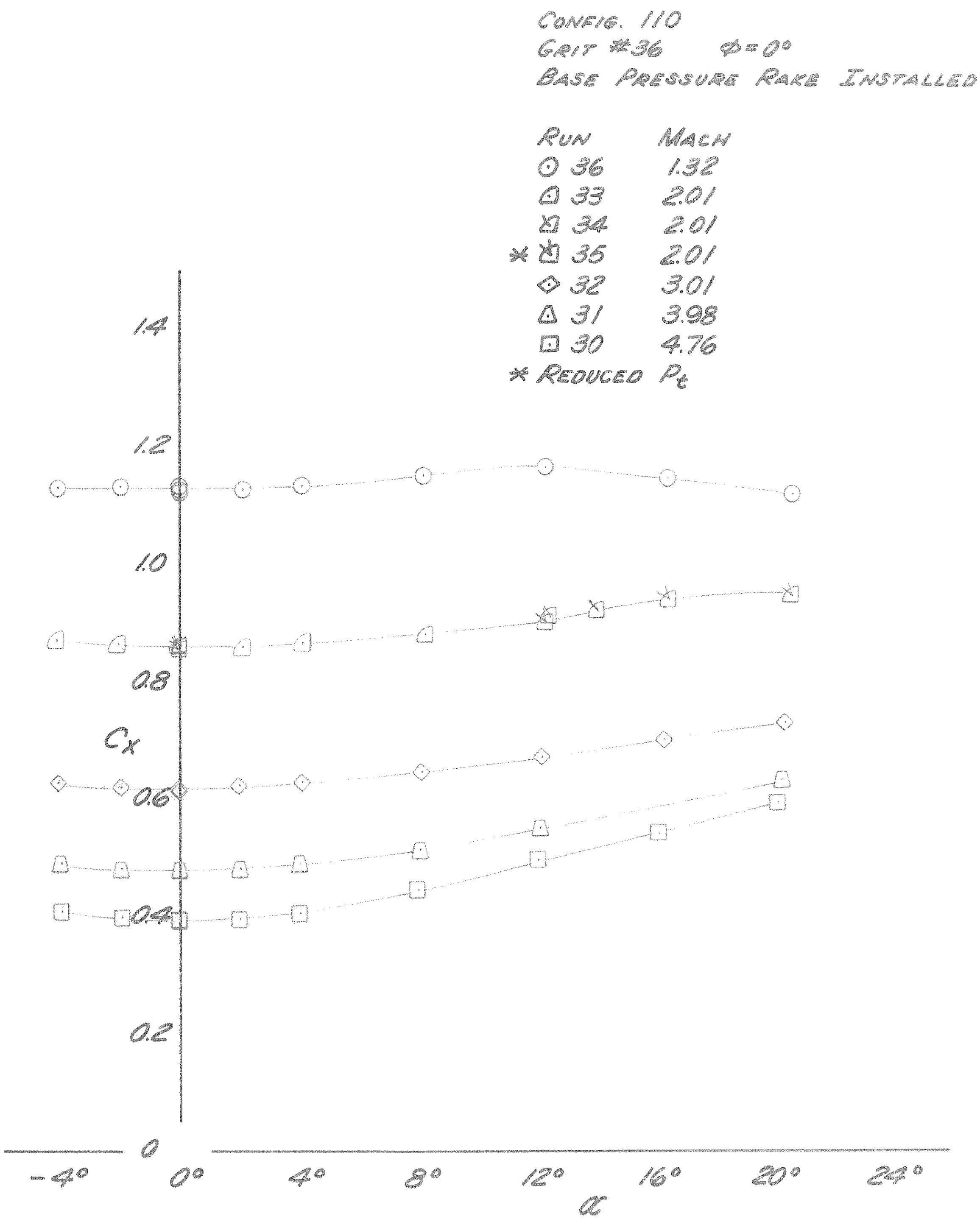


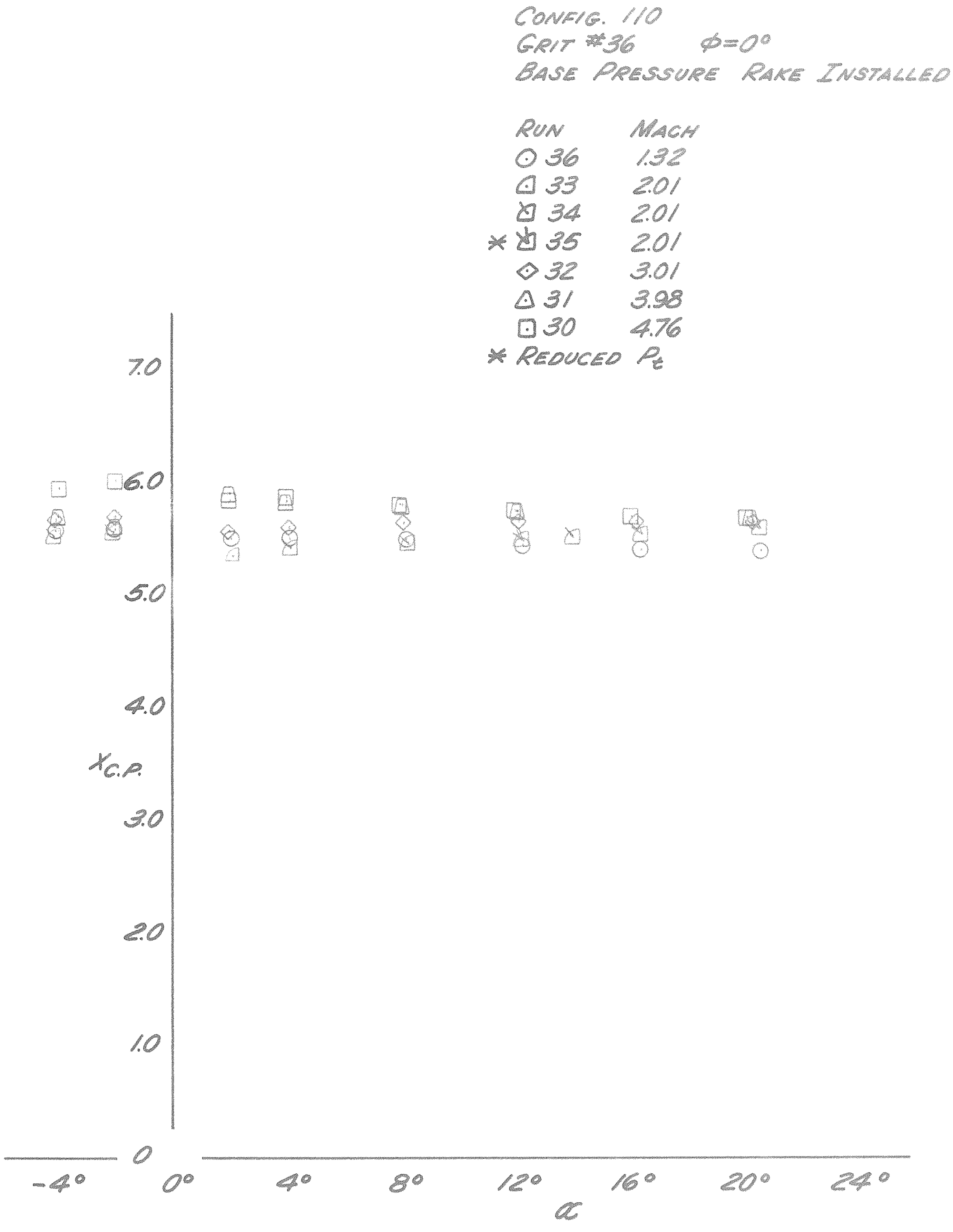
CONFIG. 110
GRIT #36 $\phi = 0°$
BASE PRESSURE RAKE INSTALLED

RUN	MACH
⊙ 36	1.32
33	2.01
34	2.01
* 35	2.01
◇ 32	3.01
△ 31	3.98
⊡ 30	4.76

* REDUCED P_t



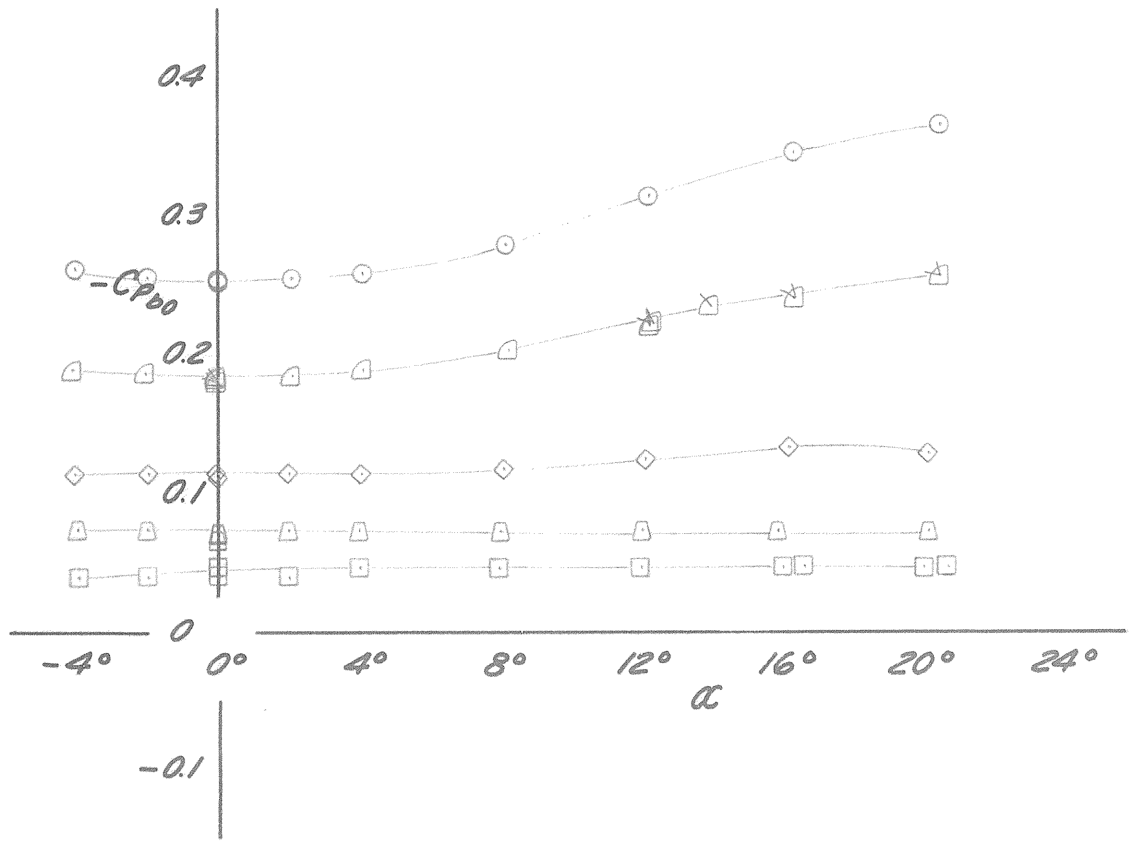

CONFIG. 110
GRIT #36 Φ=0°
BASE PRESSURE RAKE INSTALLED
RUN MACH
36 1.32
33 2.01
34 2.01
* 35 2.01
32 3.01
31 3.98
30 4.76
* REDUCED P_t
1.4
1.2
1.0
0.8
C_X
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α


CONFIG. 110
GRIT #36 φ=0°
BASE PRESSURE RAKE INSTALLED
RUN MACH
36 1.32
33 2.01
34 2.01
* 35 2.01
32 3.01
31 3.98
30 4.76
* REDUCED Pt
7.0
6.0
5.0
4.0
XC.P.
3.0
2.0
1.0
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

CONFIG. 110
GRIT #36 $\phi = 0°$
BASE PRESSURE RAKE INSTALLED

RUN	MACH
⊙ 36	1.32
33	2.01
34	2.01
* 35	2.01
◇ 32	3.01
△ 31	3.98
⊡ 30	4.76

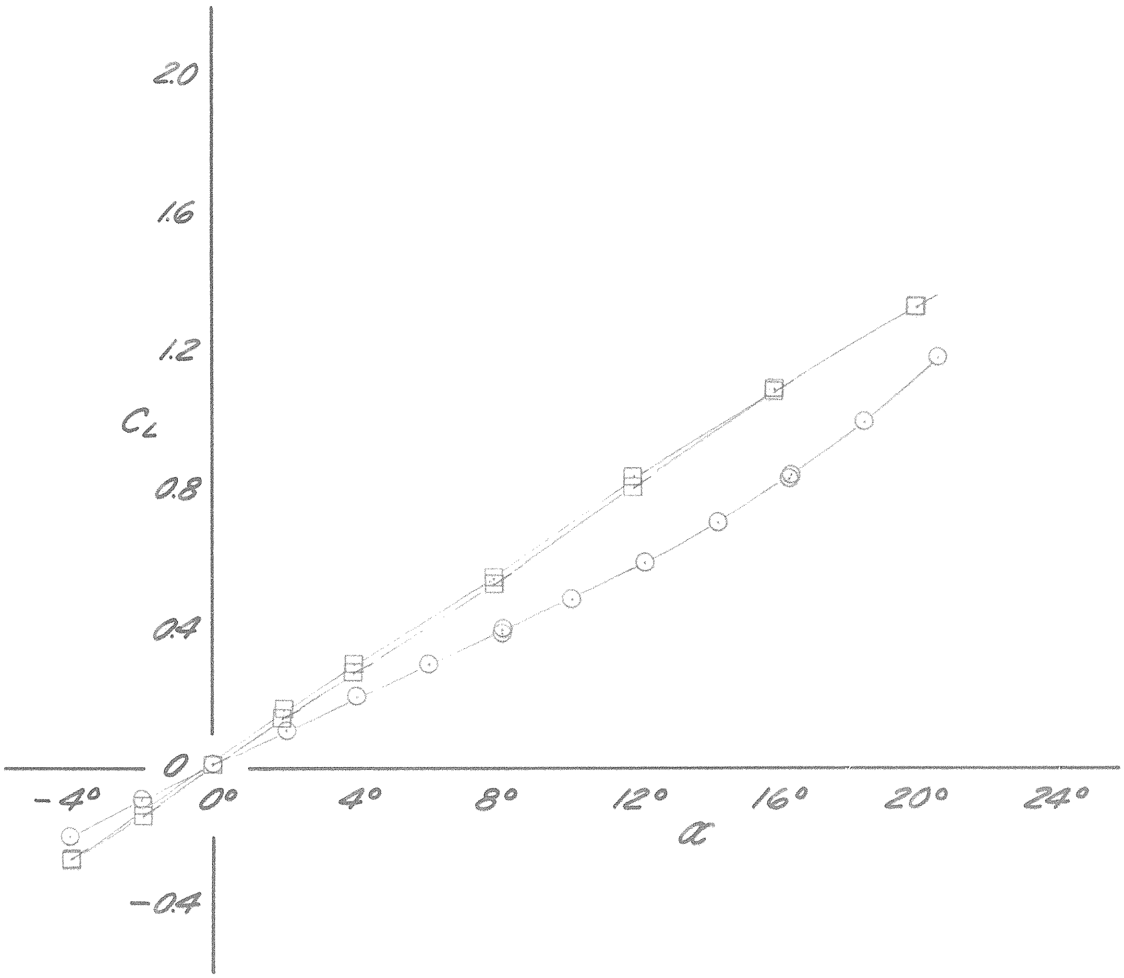
* REDUCED P_t

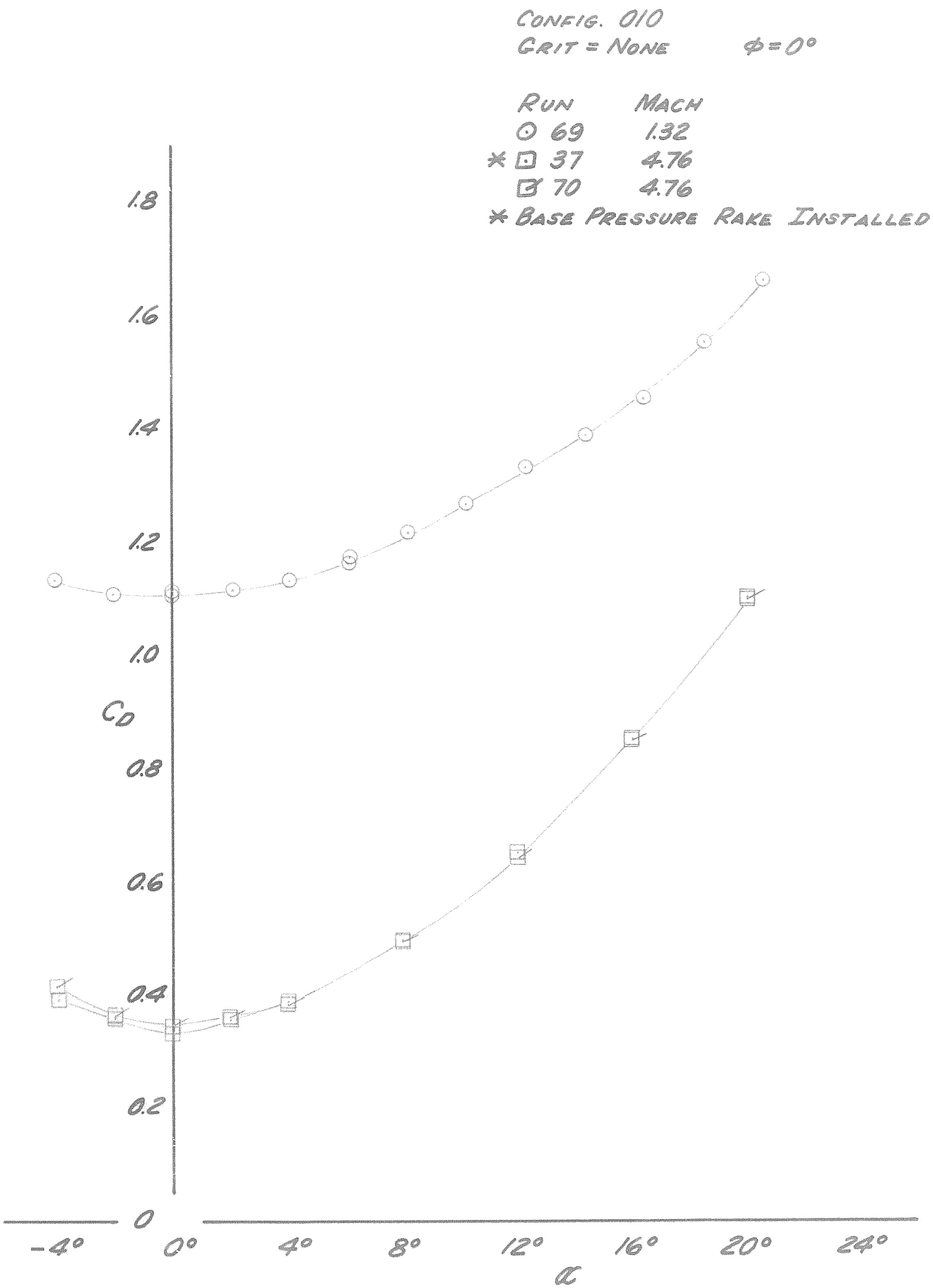


CONFIG. 010
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 69	1.32
* ⊡ 37	4.76
☑ 70	4.76

* BASE PRESSURE RAKE INSTALLED



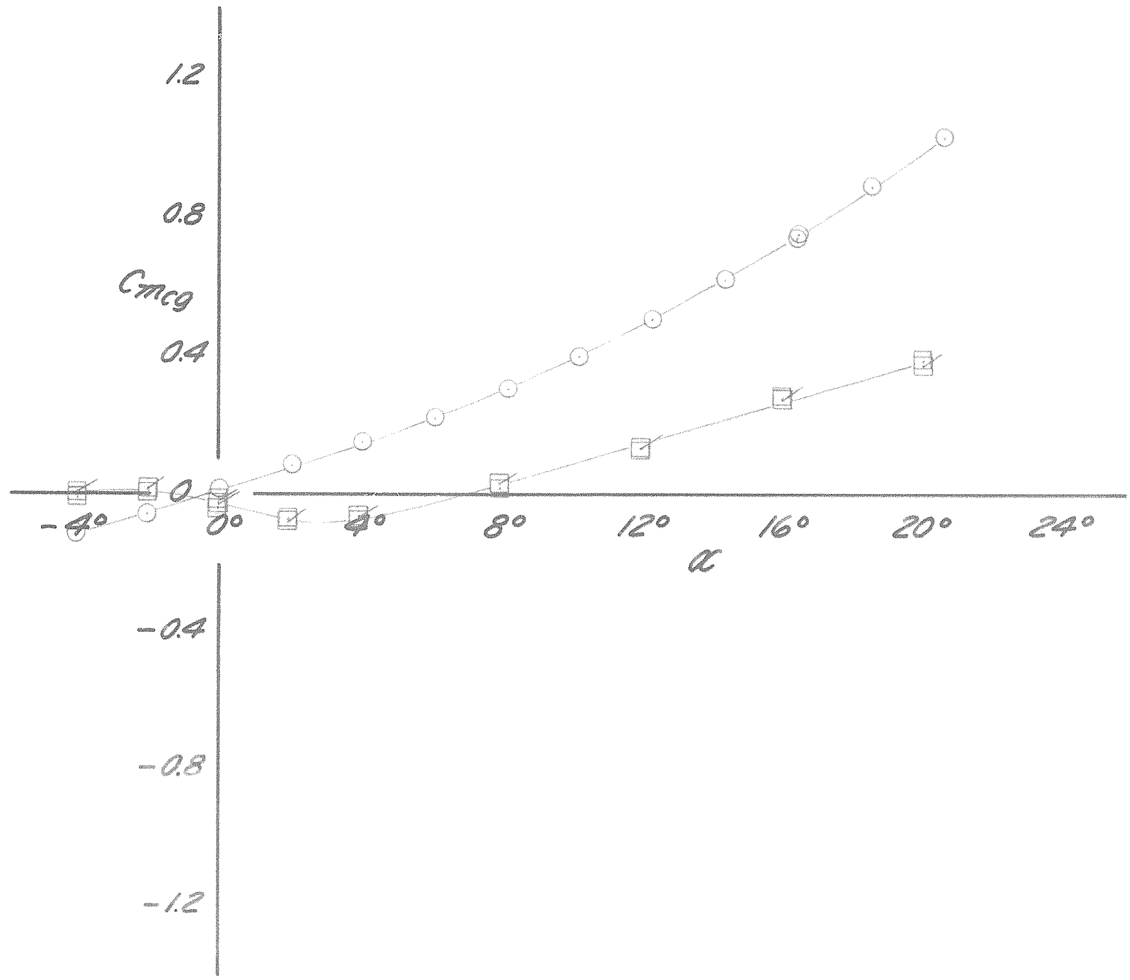

CONFIG. 010
GRIT = NONE
$\phi = 0°$
RUN
MACH
69
1.32
* 37
4.76
70
4.76
* BASE PRESSURE RAKE INSTALLED
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

CONFIG. 010
GRIT = NONE $\Phi = 0°$

RUN	MACH
⊙ 69	1.32
* ⊡ 37	4.76
⊡ 70	4.76

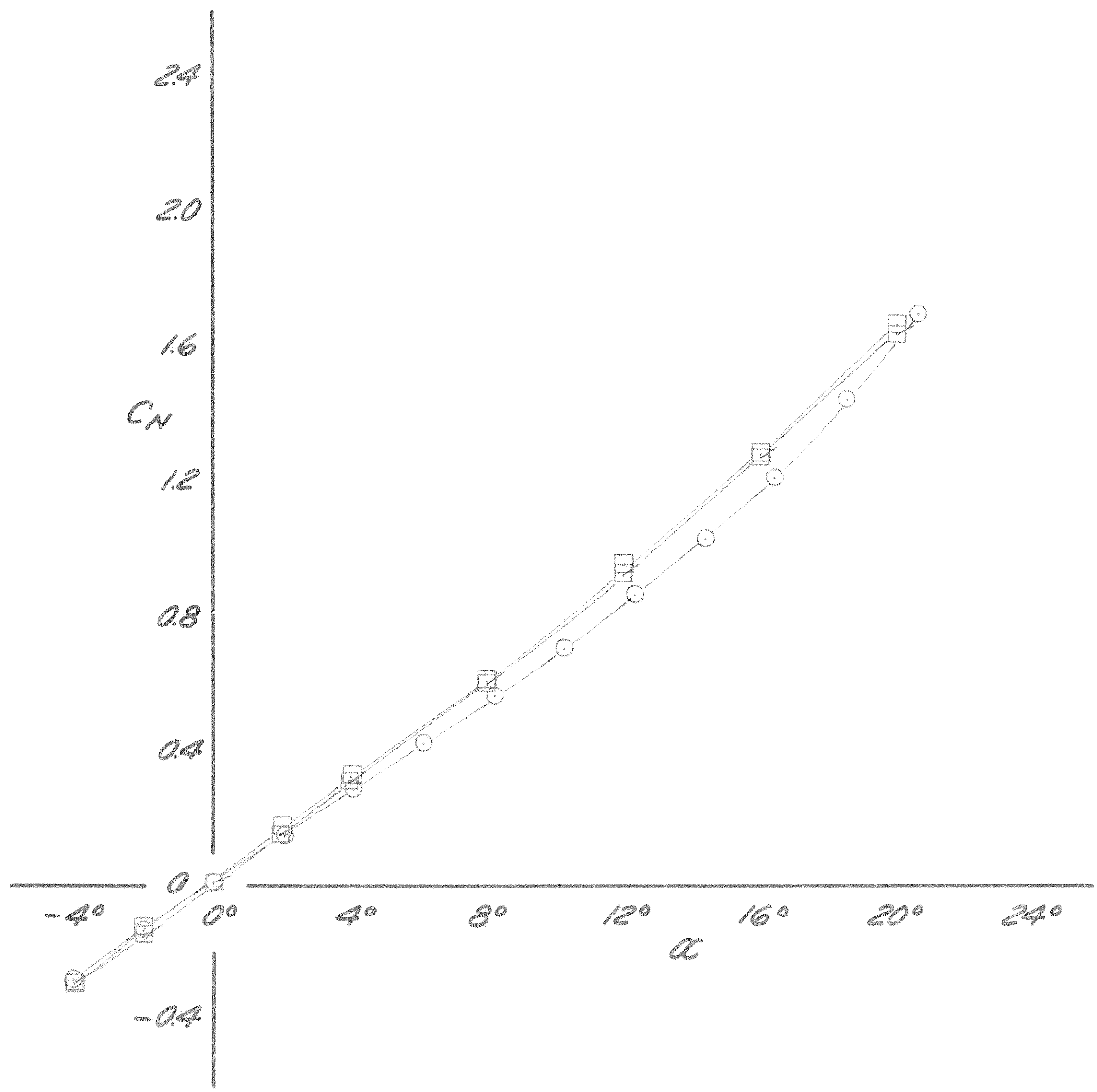
* BASE PRESSURE RAKE INSTALLED



CONFIG. 010
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 69	1.32
* ⊡ 37	4.76
☑ 70	4.76

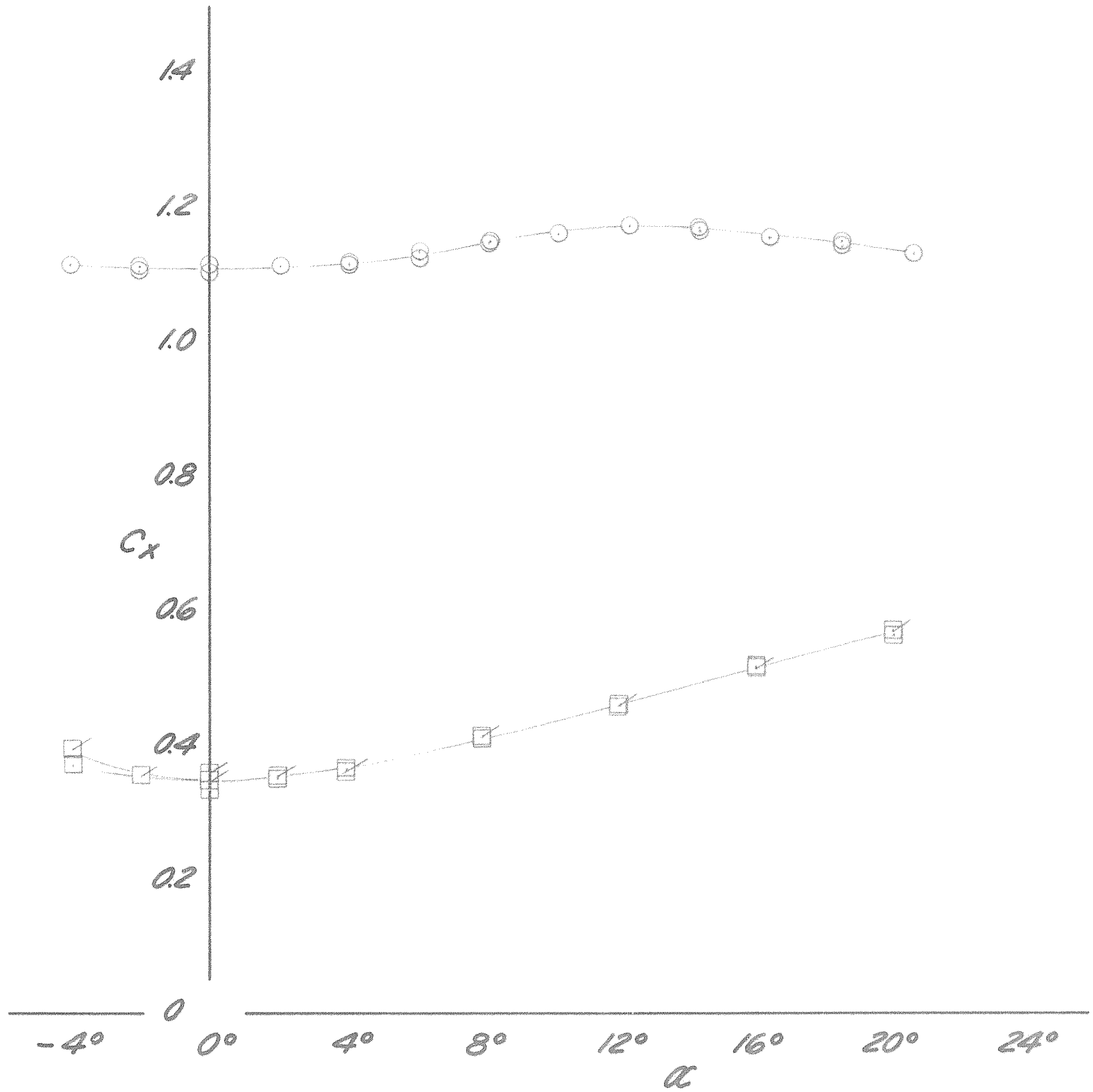
* BASE PRESSURE RAKE INSTALLED



CONFIG. 010
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 69	1.32
* ⊡ 37	4.76
☑ 70	4.76

* BASE PRESSURE RAKE INSTALLED

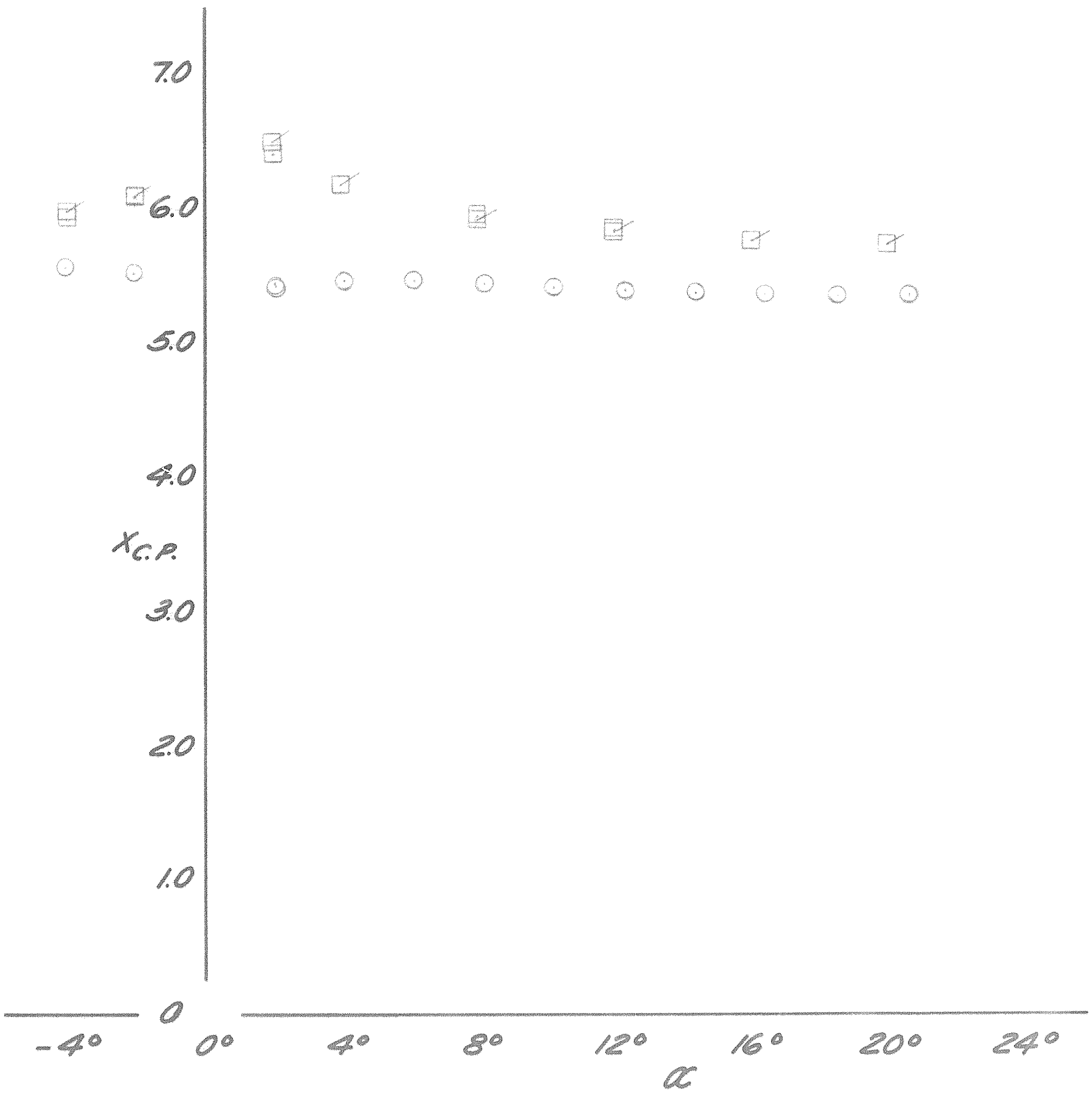


SWT 20-308

CONFIG. 010
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 69	1.32
* ⊡ 37	4.76
☑ 70	4.76

* BASE PRESSURE RAKE INSTALLED

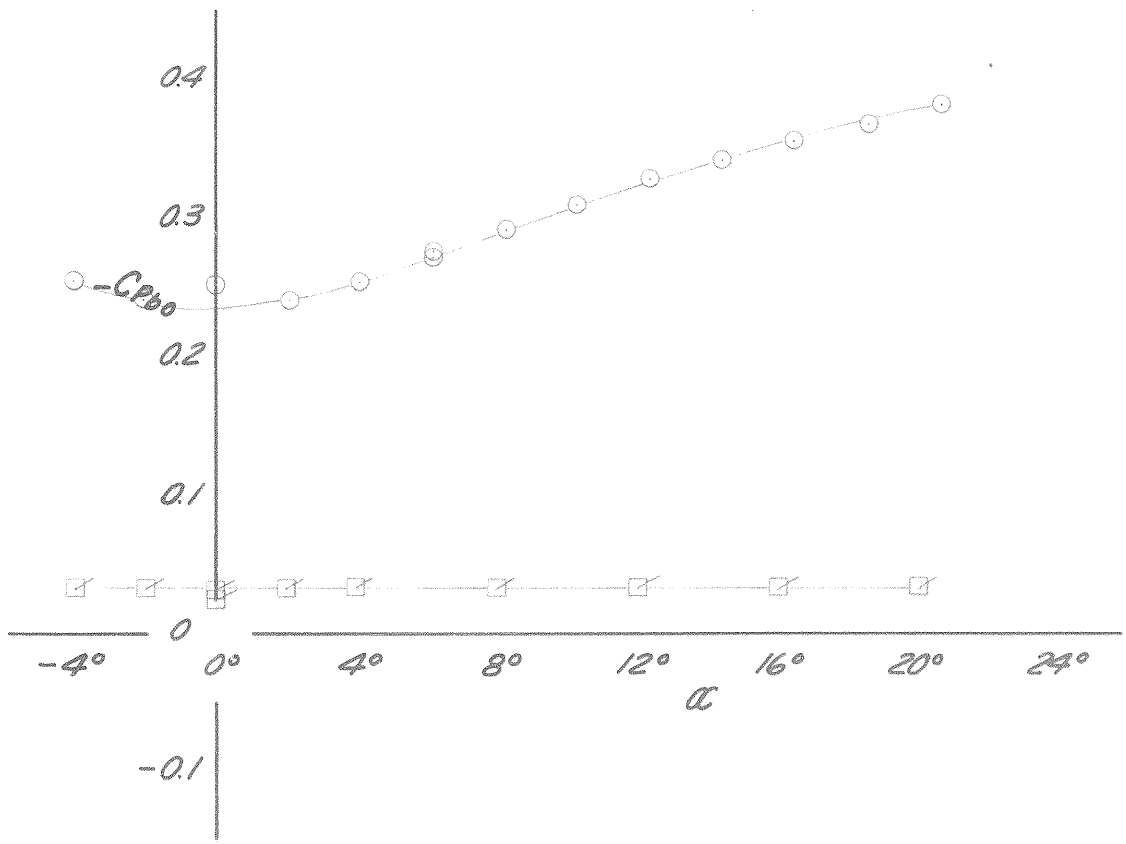


PLOT 30f

CONFIG. 010
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 69	1.32
* ⊡ 37	4.76
☑ 70	4.76

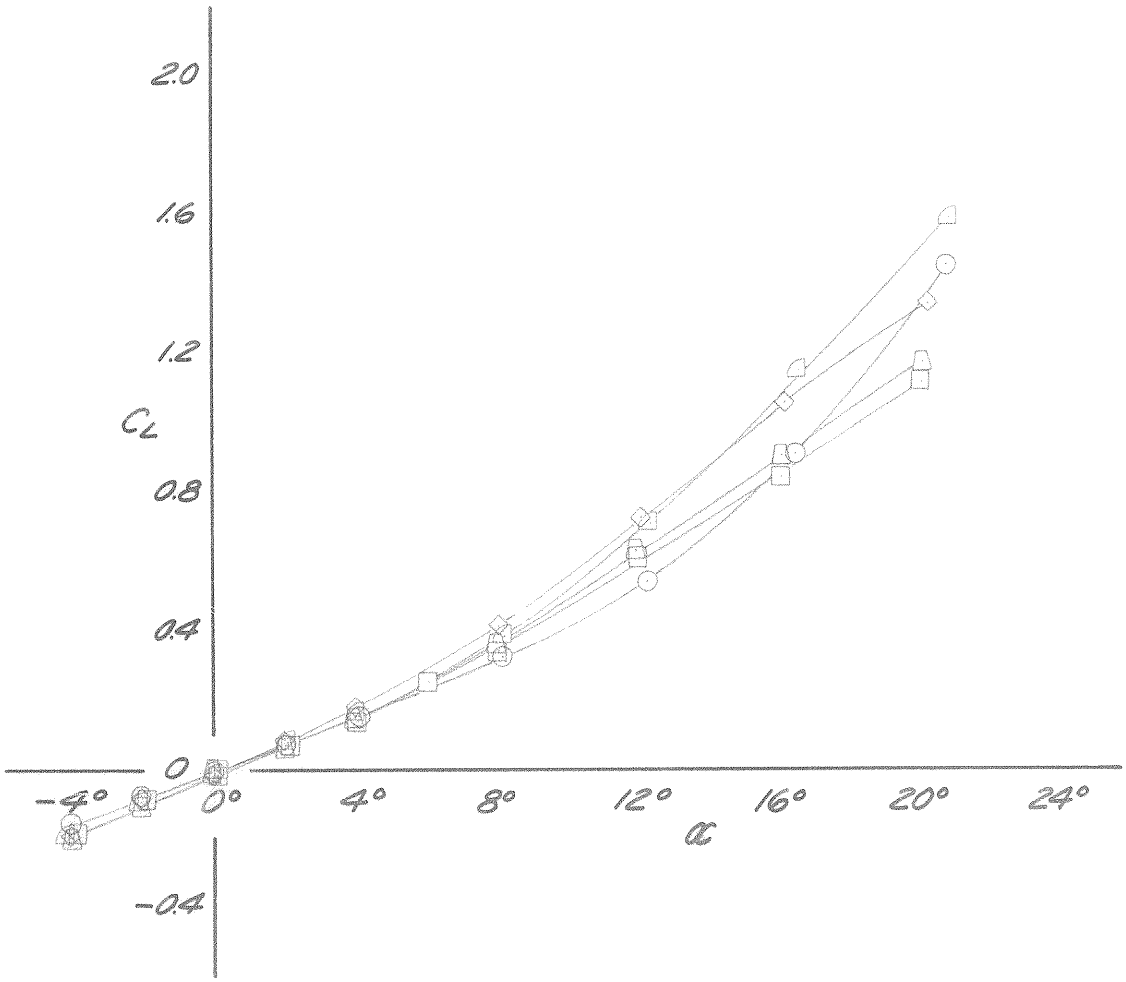
* BASE PRESSURE RAKE INSTALLED



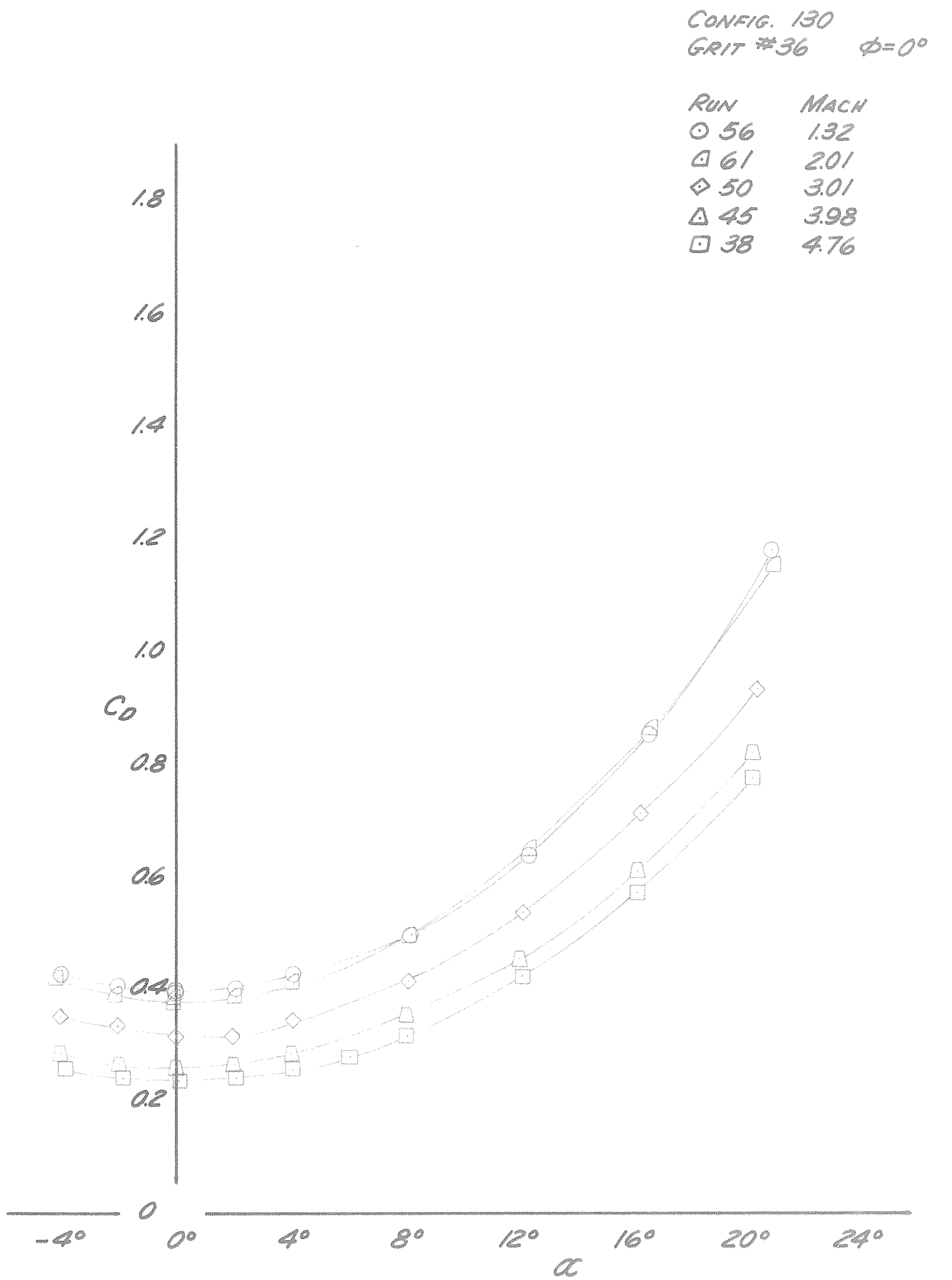
SWT 20-308

CONFIG. 130
GRIT # 36 $\phi = 0°$

RUN	MACH
⊙ 56	1.32
61	2.01
◇ 50	3.01
△ 45	3.98
⊡ 38	4.76



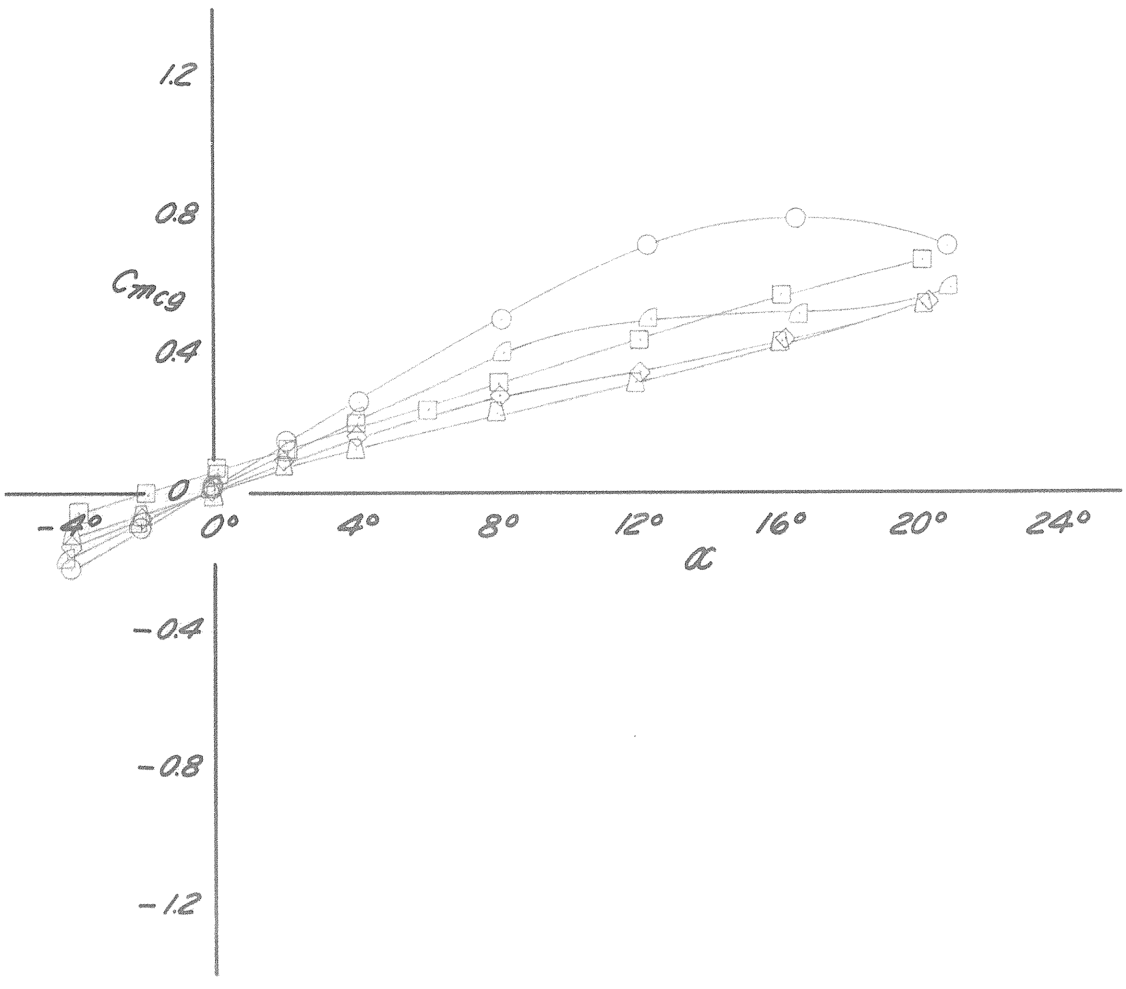
PLOT 31a


CONFIG. 130
GRIT #36 φ=0°
RUN MACH
56 1.32
61 2.01
50 3.01
45 3.98
38 4.76
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

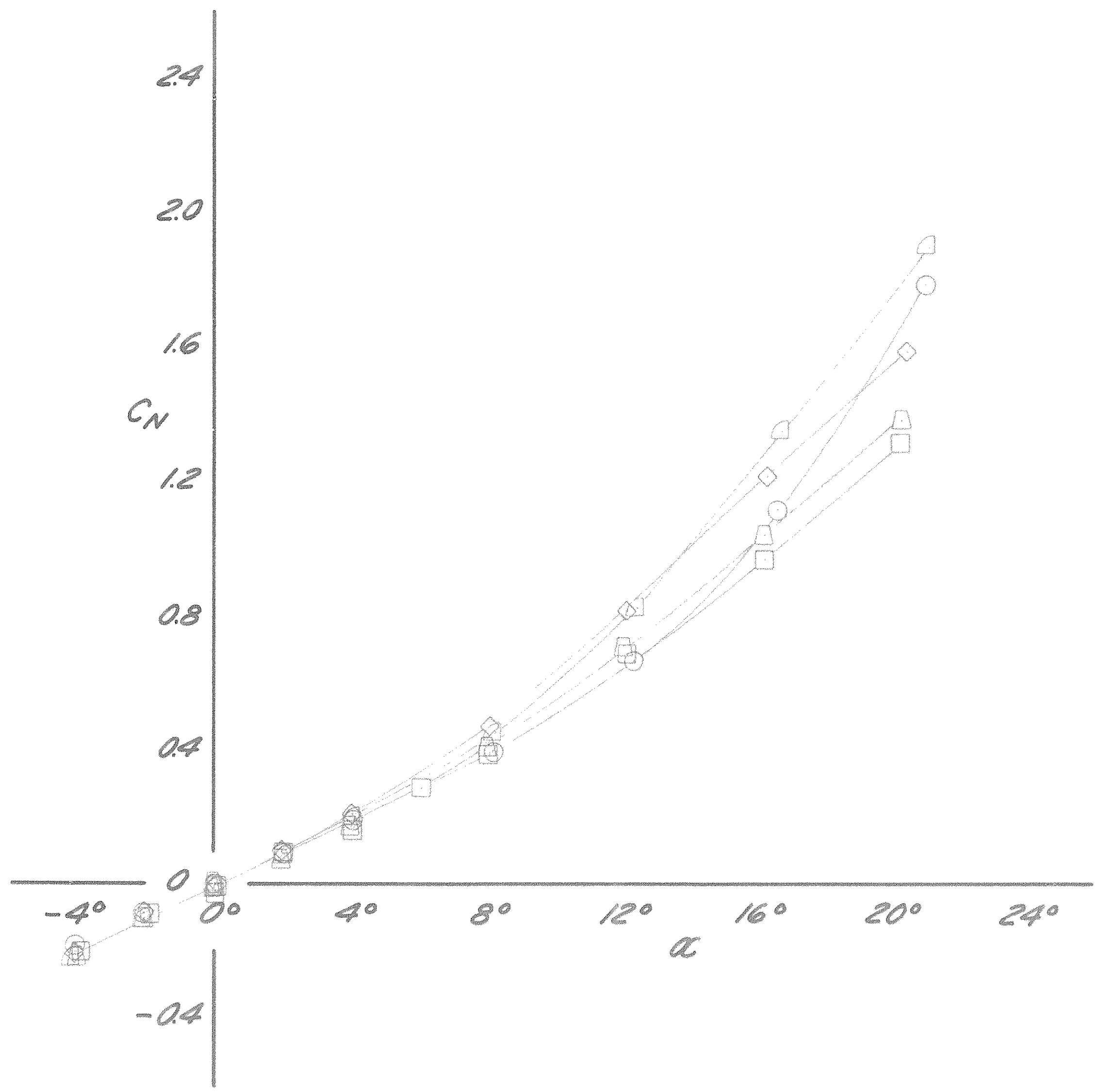
CONFIG. 130
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 56	1.32
61	2.01
◇ 50	3.01
△ 45	3.98
⊡ 38	4.76

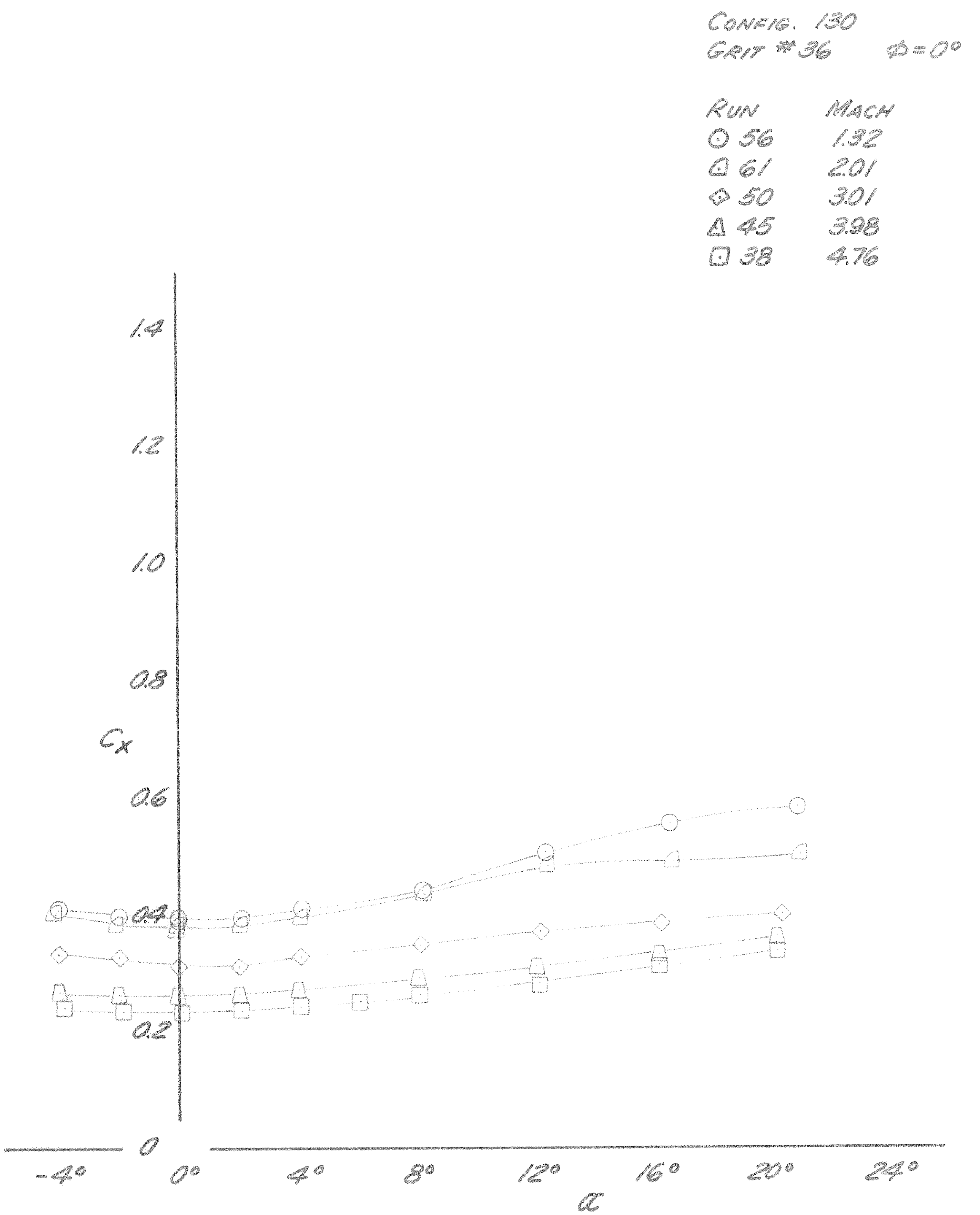


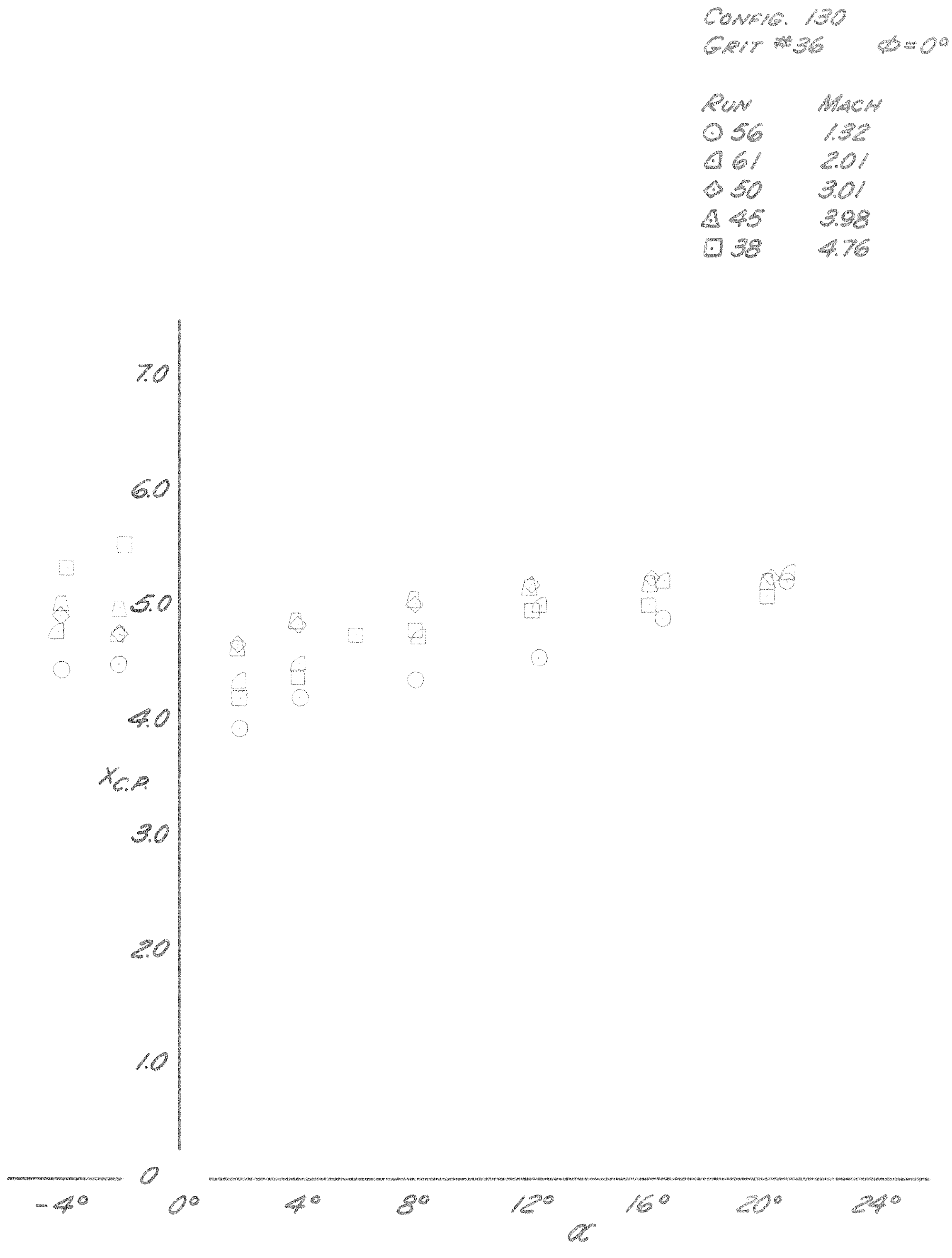
CONFIG. 130
GRIT #36 $\phi = 0°$

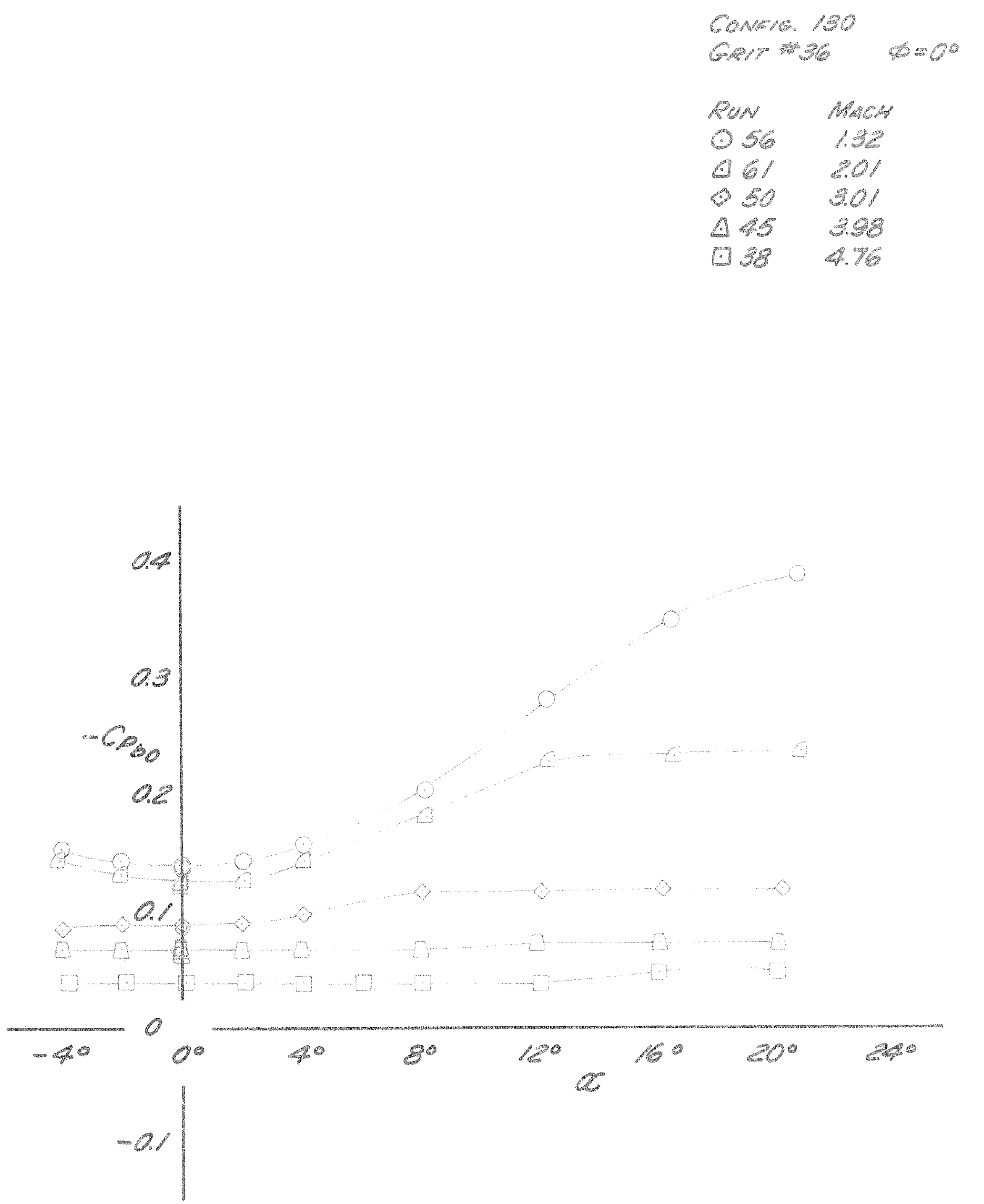
RUN	MACH
⊙ 56	1.32
61	2.01
◇ 50	3.01
△ 45	3.98
⊡ 38	4.76



SWT 20-308


CONFIG. 130
GRIT #36 Φ=0°
RUN MACH
⊙ 56 1.32
61 2.01
◇ 50 3.01
△ 45 3.98
⊡ 38 4.76
1.4
1.2
1.0
0.8
Cx
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

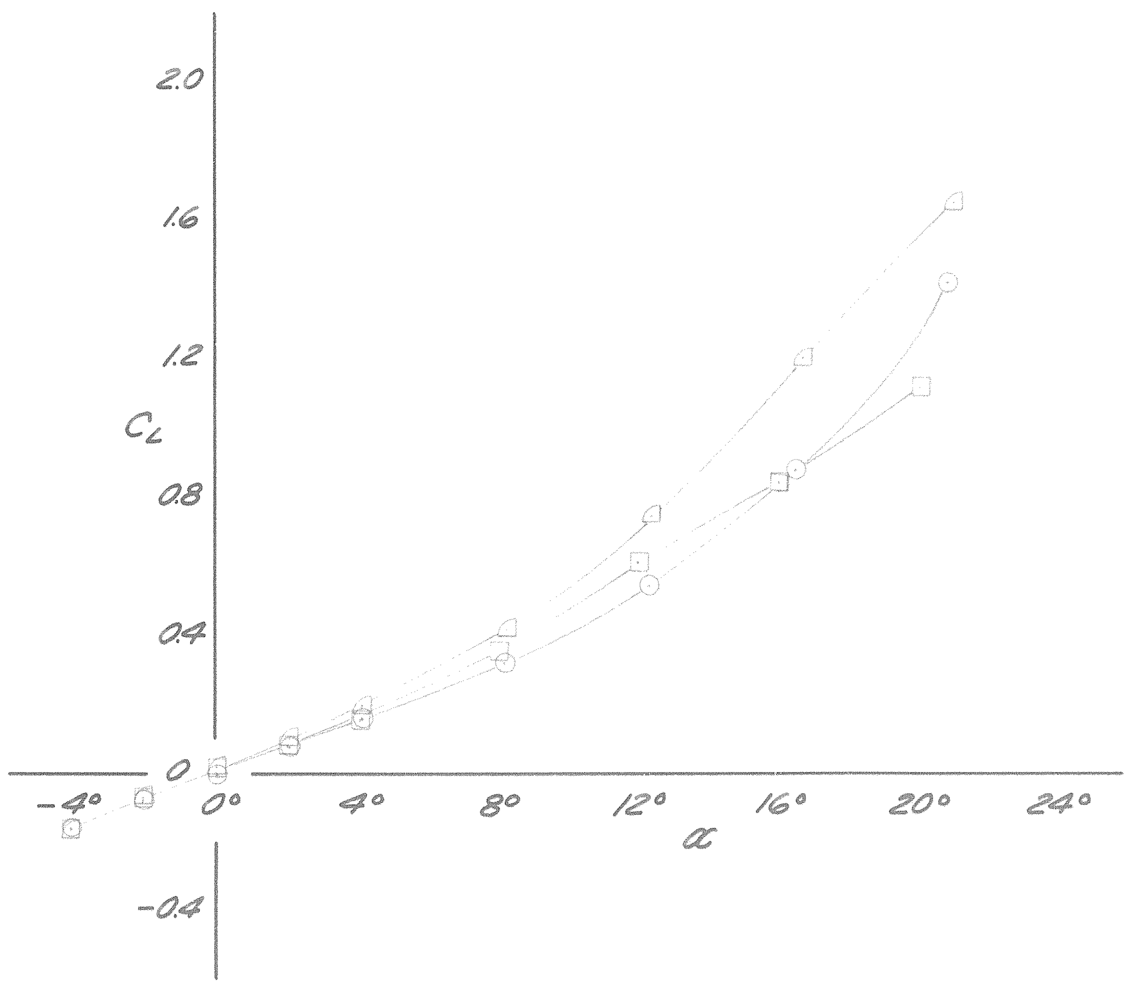

CONFIG. 130
GRIT #36 Φ=0°
RUN MACH
⊙ 56 1.32
61 2.01
50 3.01
△ 45 3.98
⊡ 38 4.76
7.0
6.0
5.0
4.0
X C.P.
3.0
2.0
1.0
0
-4°
0°
4°
8°
12°
16°
20°
24°
α


CONFIG. 130
GRIT #36 ϕ=0°
RUN MACH
56 1.32
61 2.01
50 3.01
45 3.98
38 4.76
0.4
0.3
$-C_{p_{b0}}$
0.2
0.1
0
-0.1
-4°
0°
4°
8°
12°
16°
20°
24°
α

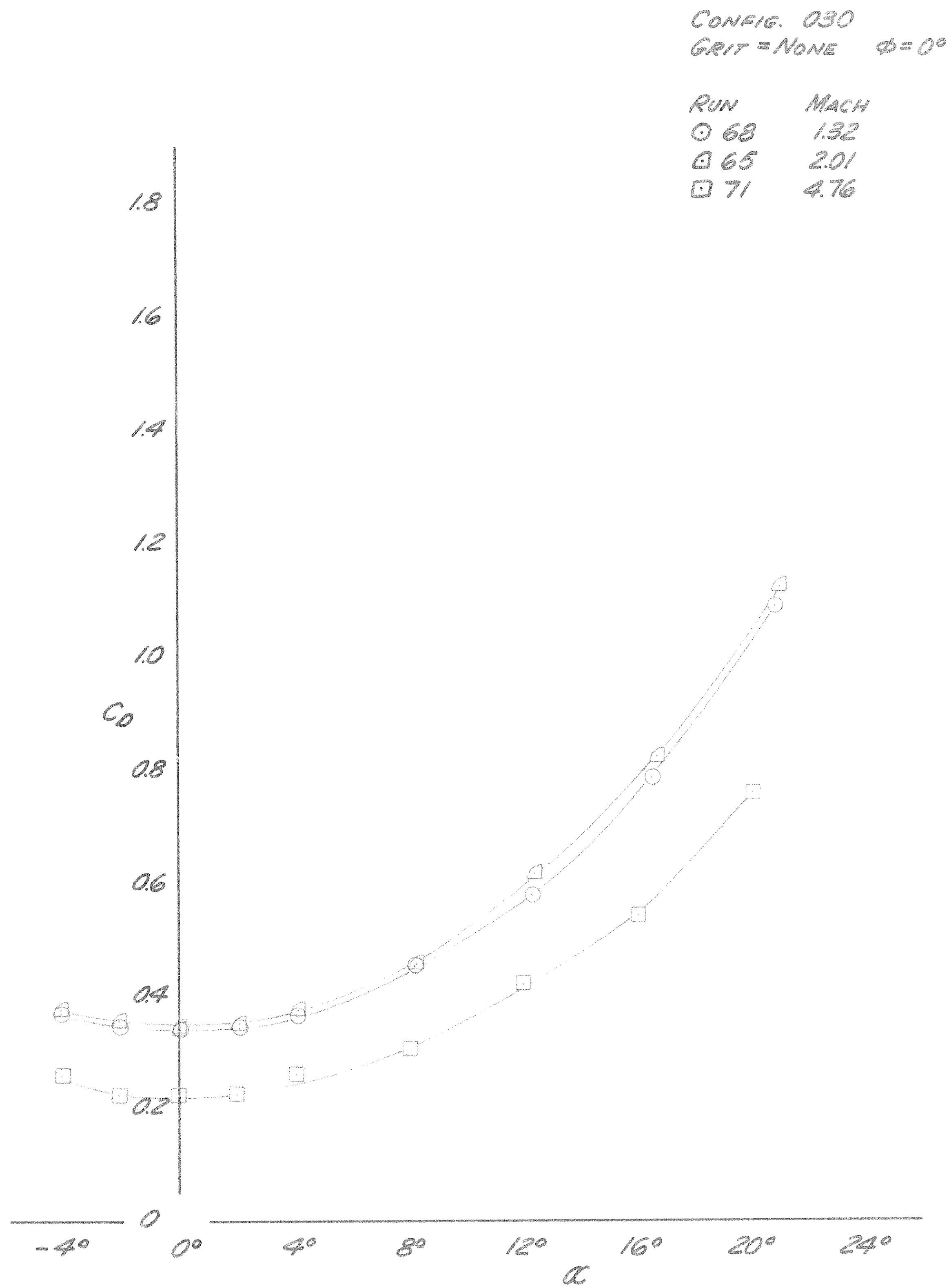
SWT 20-308

CONFIG. 030
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 68	1.32
◺ 65	2.01
⊡ 71	4.76



SWT 20-308

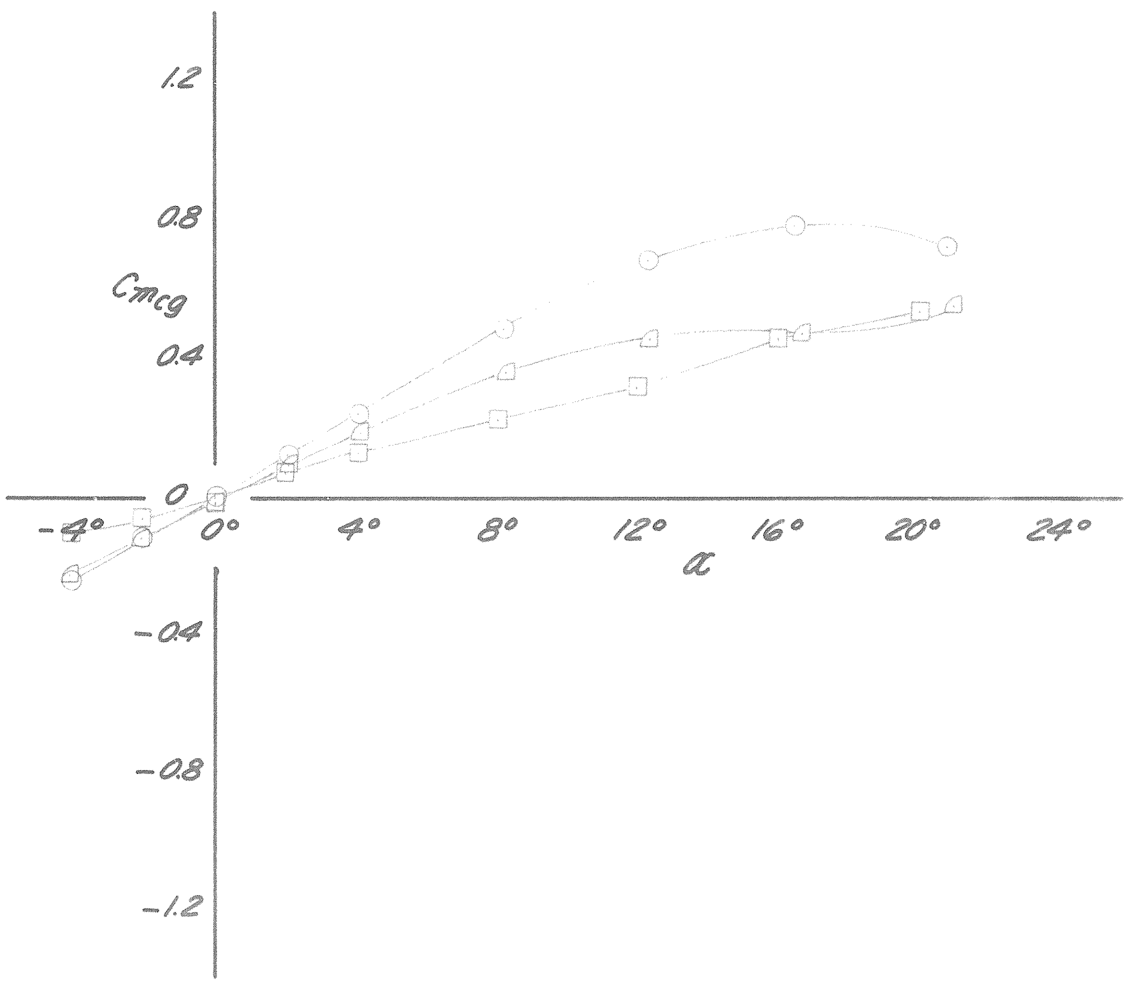


CONFIG. 030
GRIT = NONE
$\phi = 0°$
RUN
MACH
68
1.32
65
2.01
71
4.76
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

CONFIG. 030
GRIT = NONE $\Phi = 0°$

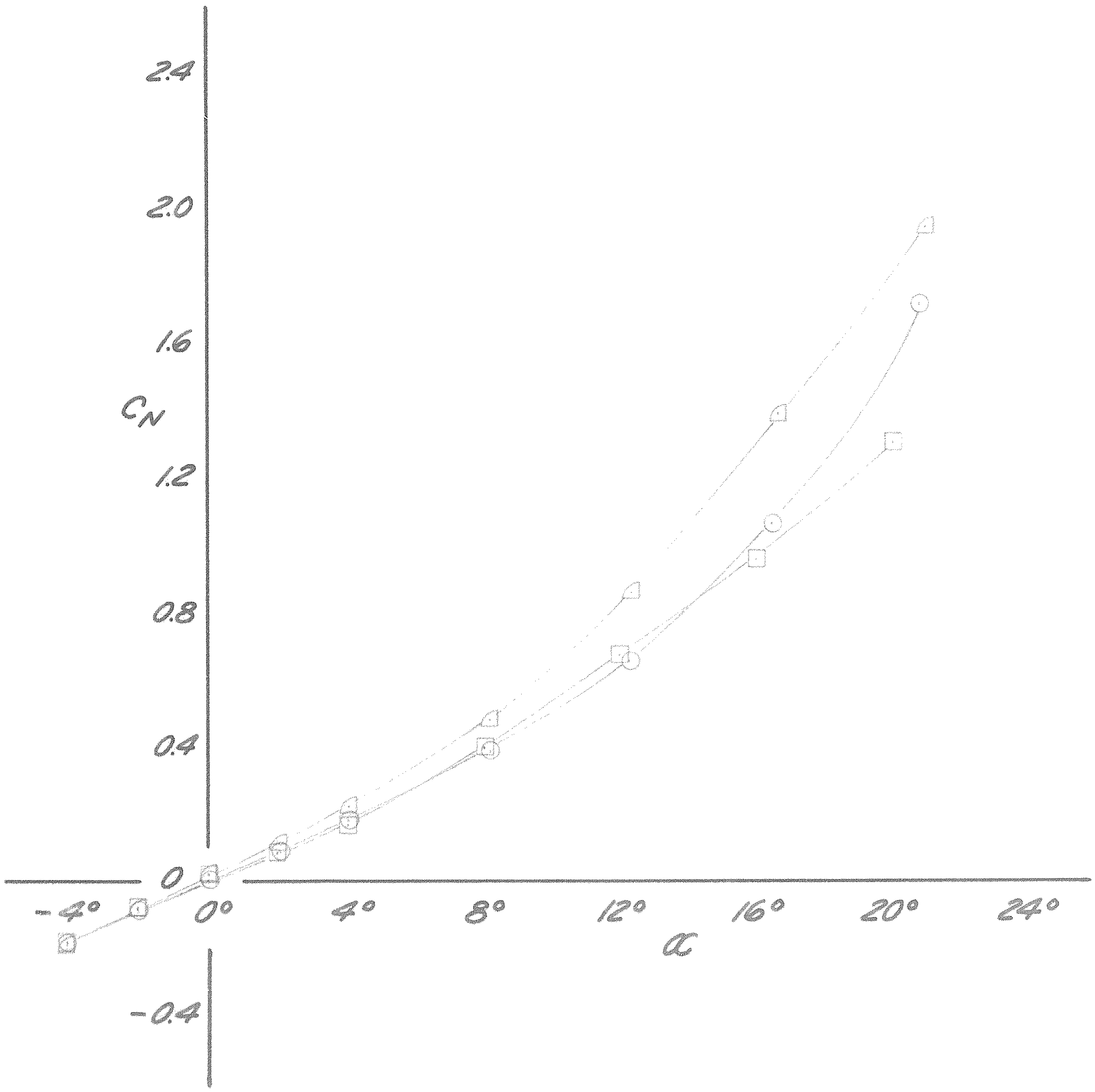
RUN	MACH
⊙ 68	1.32
△ 65	2.01
⊡ 71	4.76



SWT 20-308

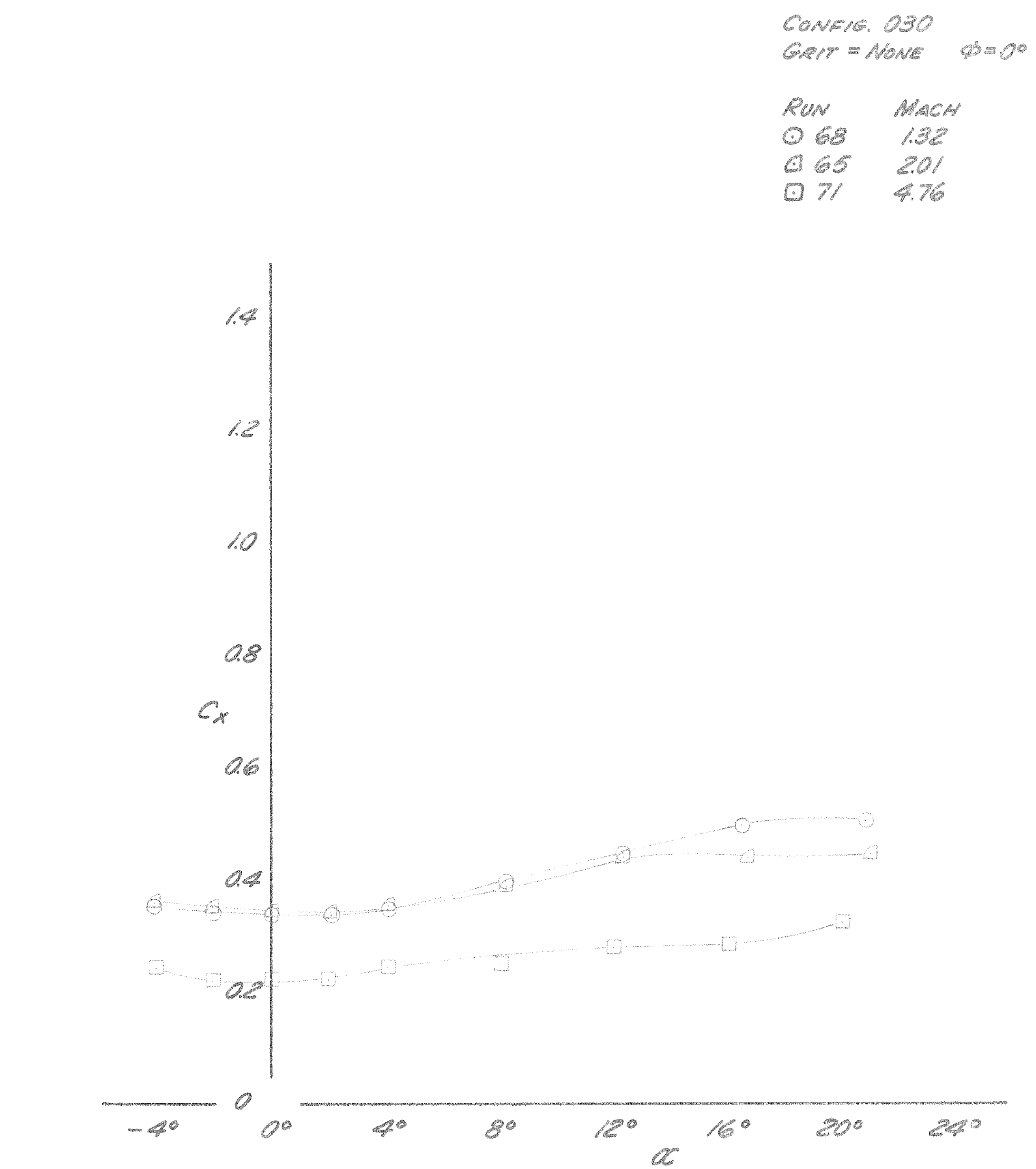
CONFIG. 030
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 68	1.32
◭ 65	2.01
⊡ 71	4.76

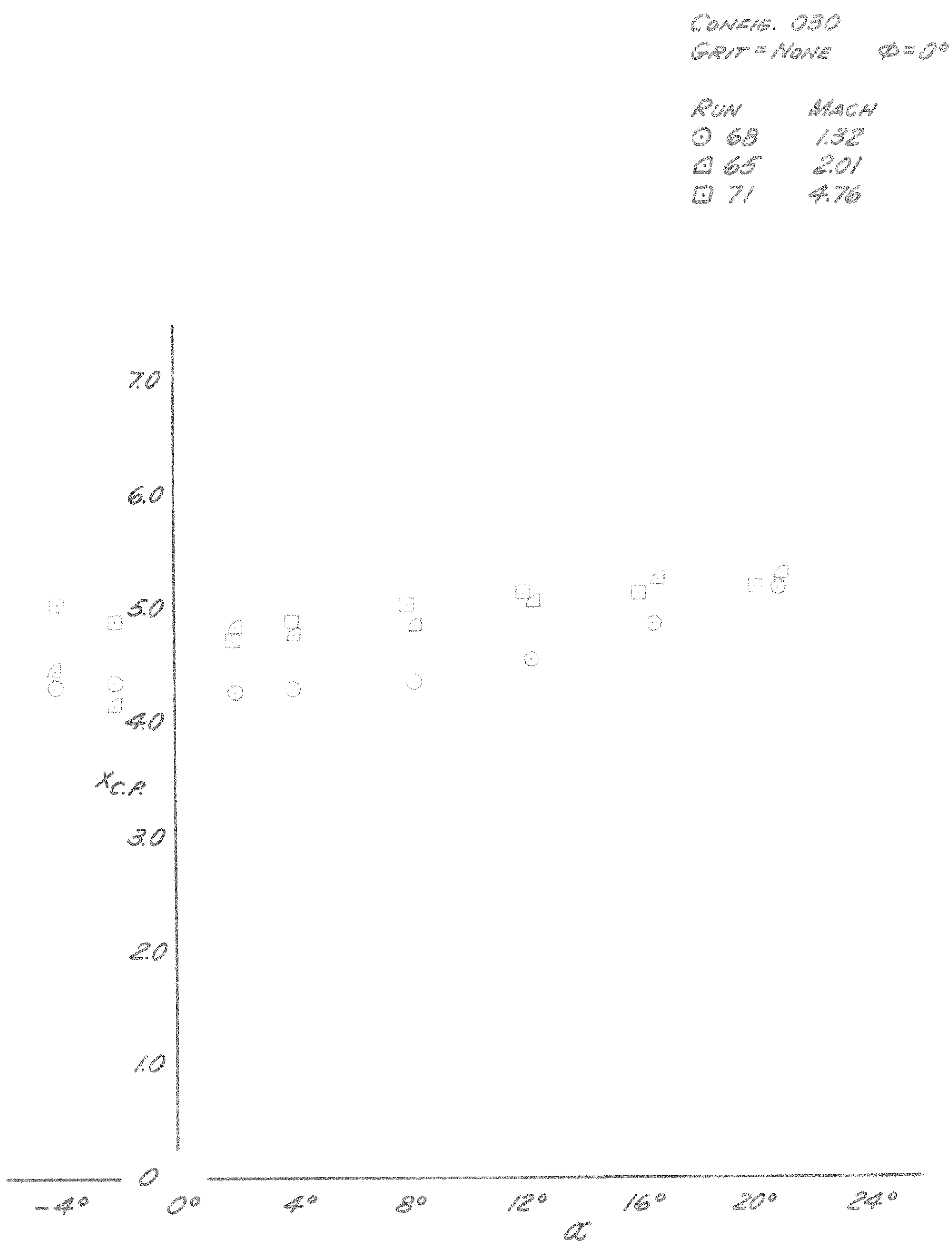


PLOT 32d

SWT 20-308


CONFIG. 030
GRIT = NONE   Φ=0°
RUN   MACH
⊙ 68   1.32
◬ 65   2.01
⊡ 71   4.76
1.4
1.2
1.0
0.8
C_x
0.6
0.4
0.2
0
−4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

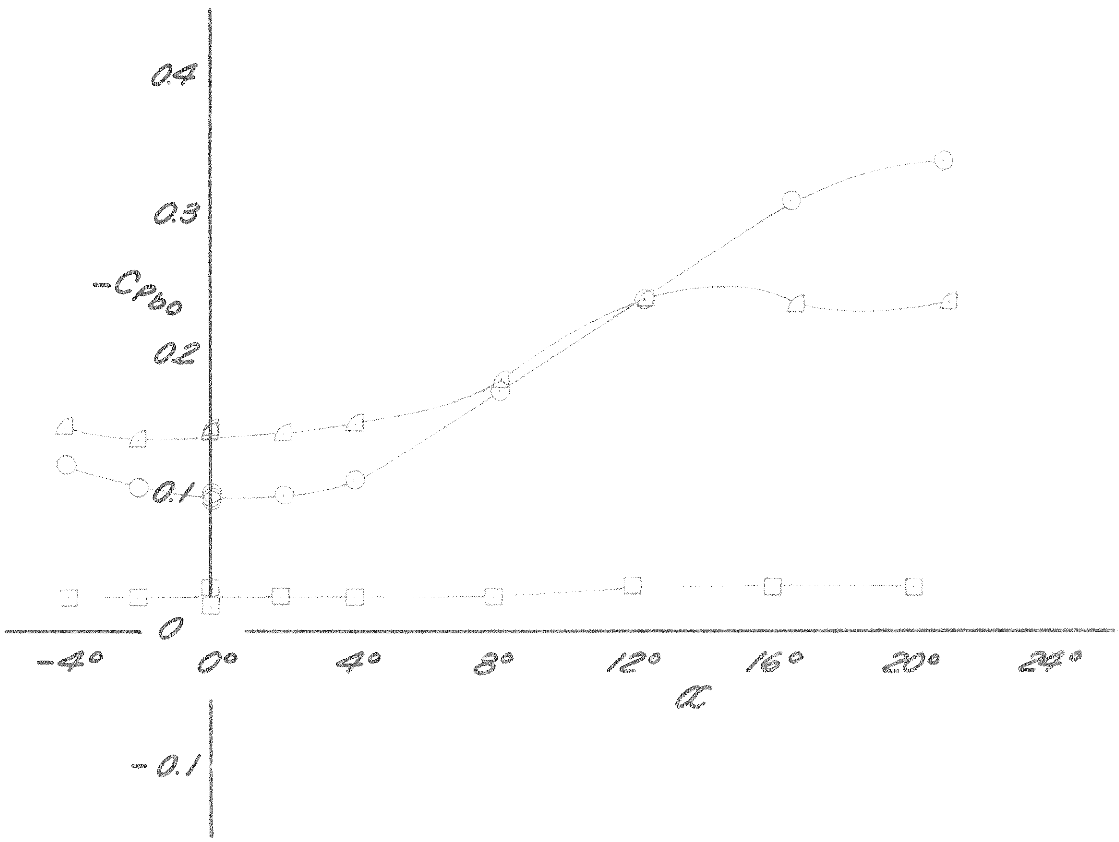


PLOT 32F

SWT 20-308

CONFIG. 030
GRIT = NONE $\phi = 0°$

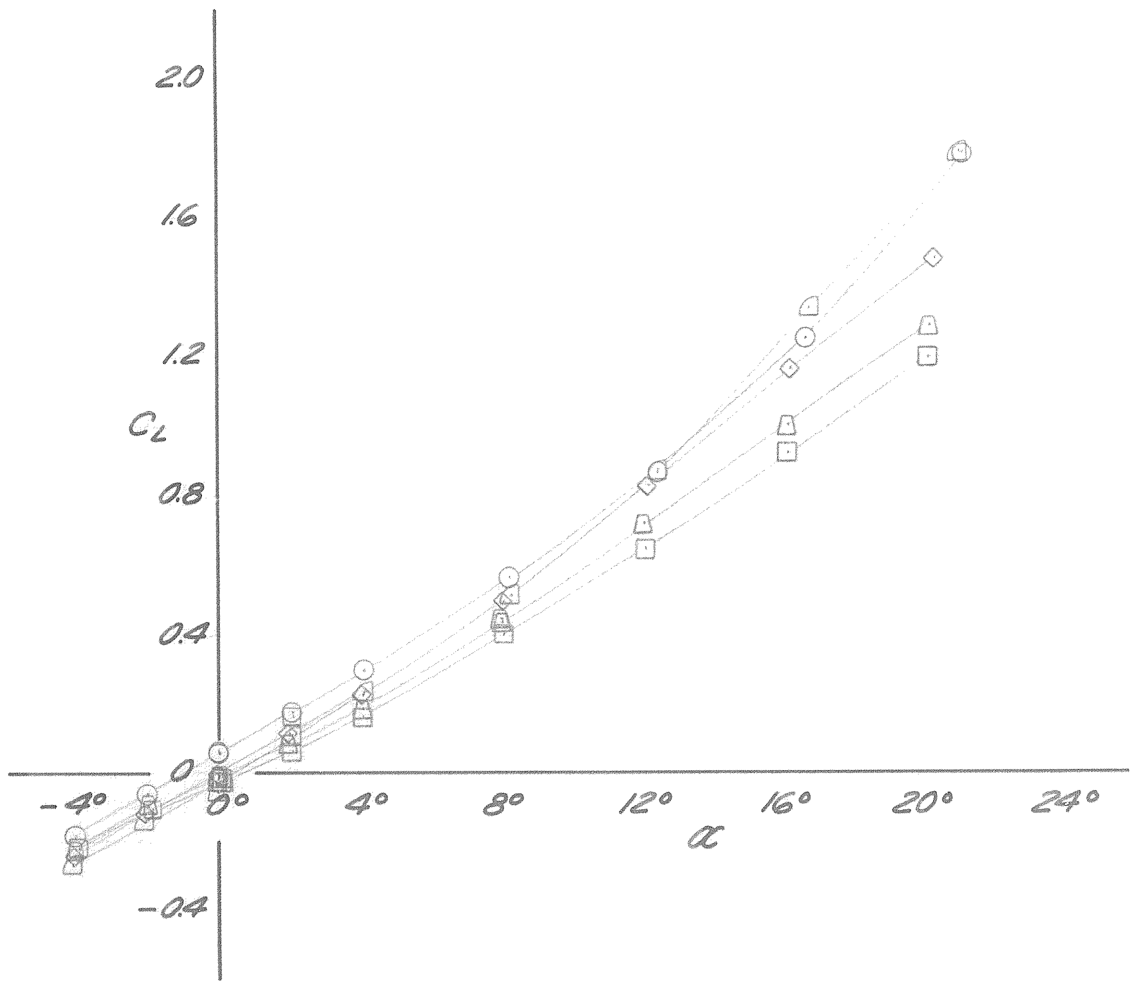
RUN	MACH
⊙ 68	1.32
◿ 65	2.01
⊡ 71	4.76

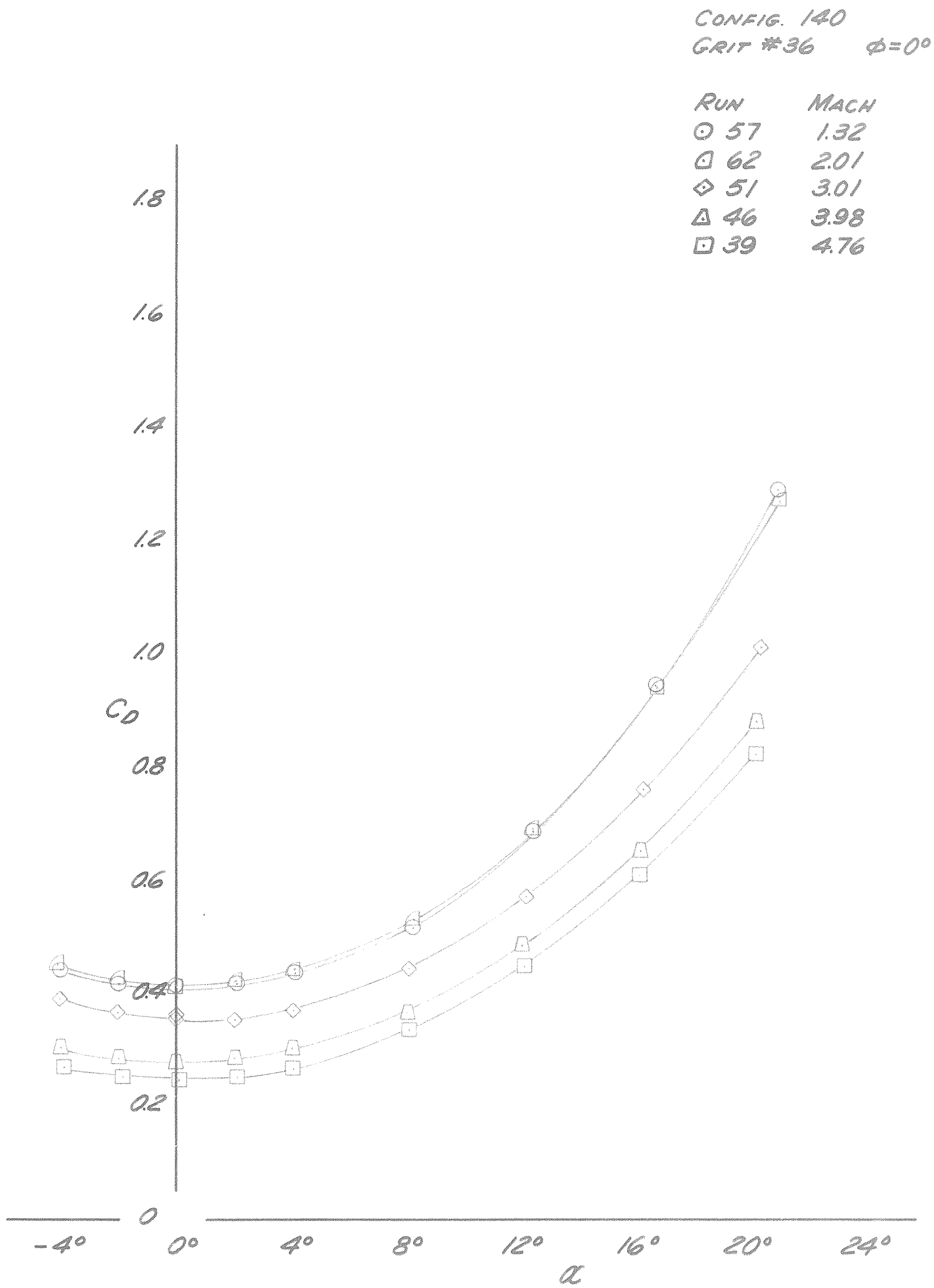


SWT 20-308

CONFIG. 140
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 57	1.32
62	2.01
◇ 51	3.01
△ 46	3.98
⊡ 39	4.76

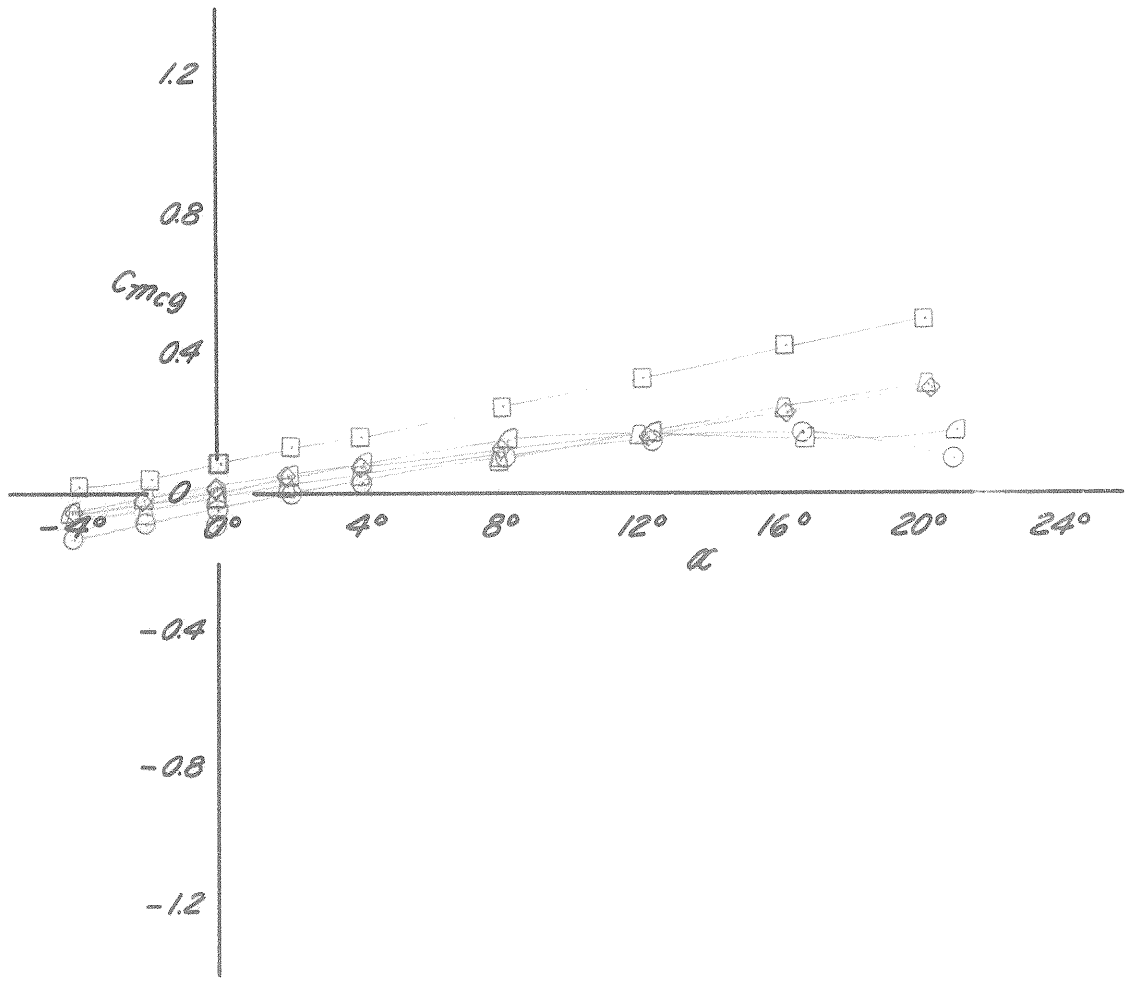



CONFIG. 140
GRIT #36 φ=0°
RUN MACH
57 1.32
62 2.01
51 3.01
46 3.98
39 4.76
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

CONFIG. 140
GRIT #36 $\Phi = 0°$

RUN	MACH
⊙ 57	1.32
62	2.01
51	3.01
46	3.98
39	4.76

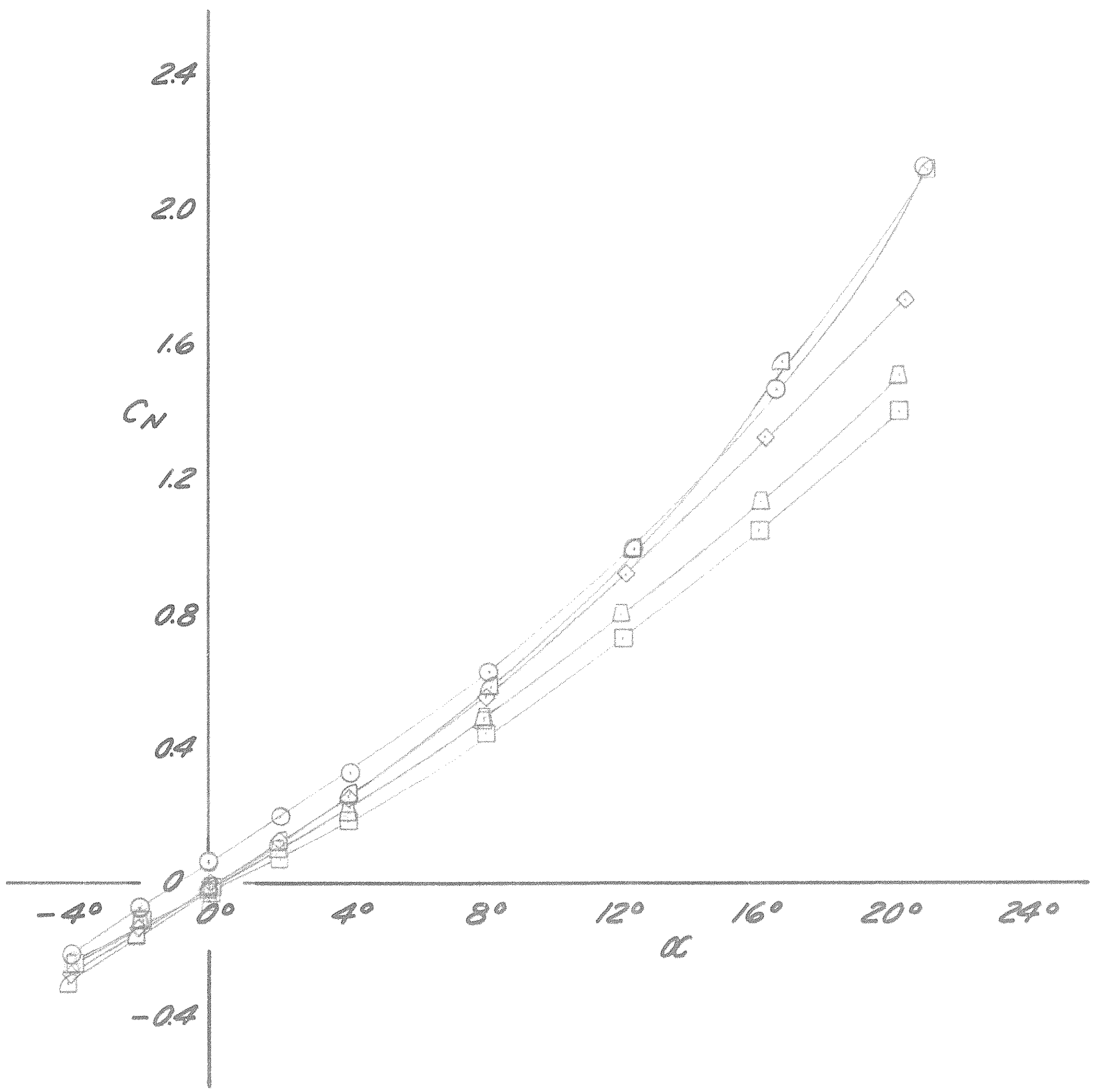


PLOT 33C

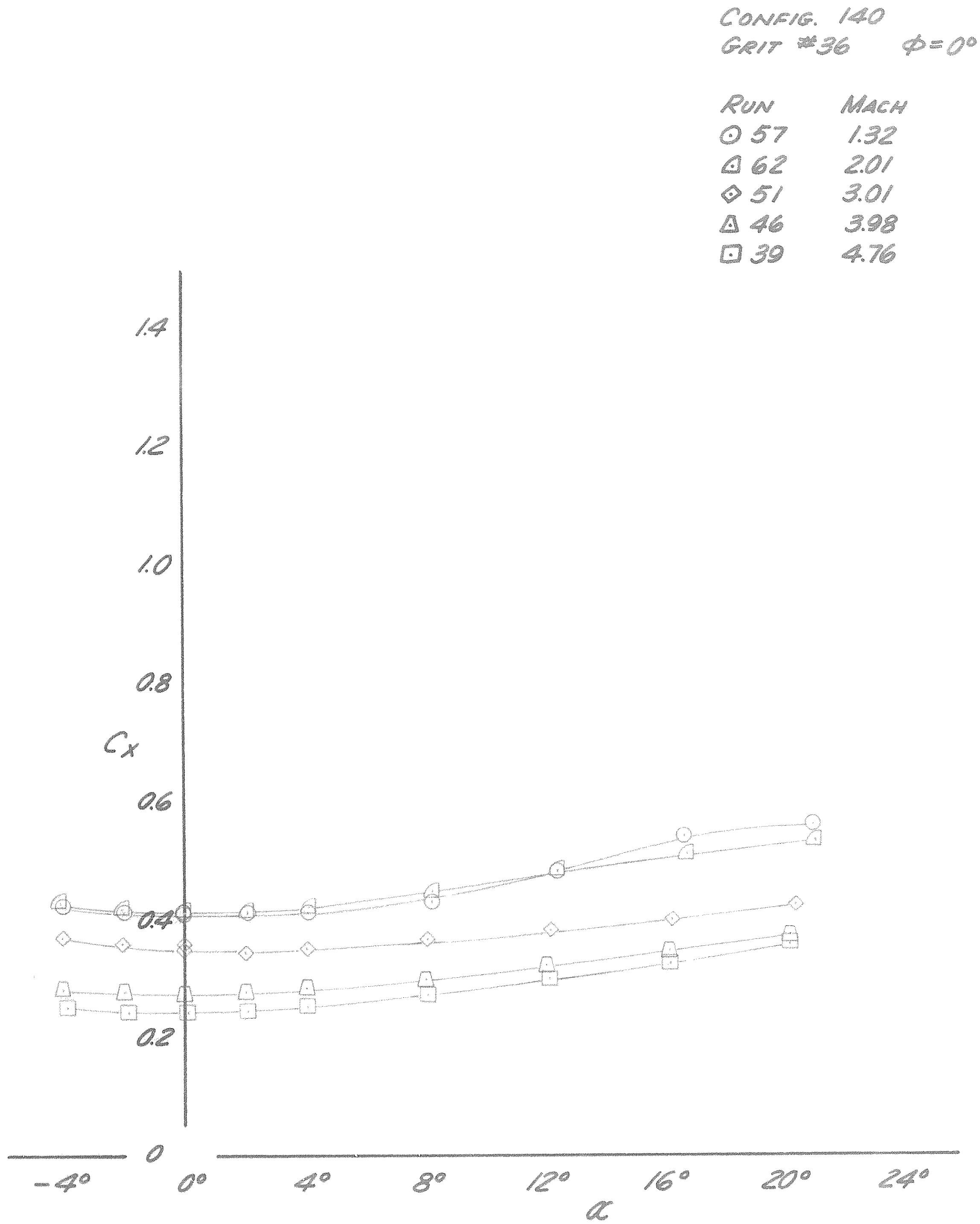
SWT 20-308

CONFIG. 140
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 57	1.32
62	2.01
◇ 51	3.01
△ 46	3.98
⊡ 39	4.76



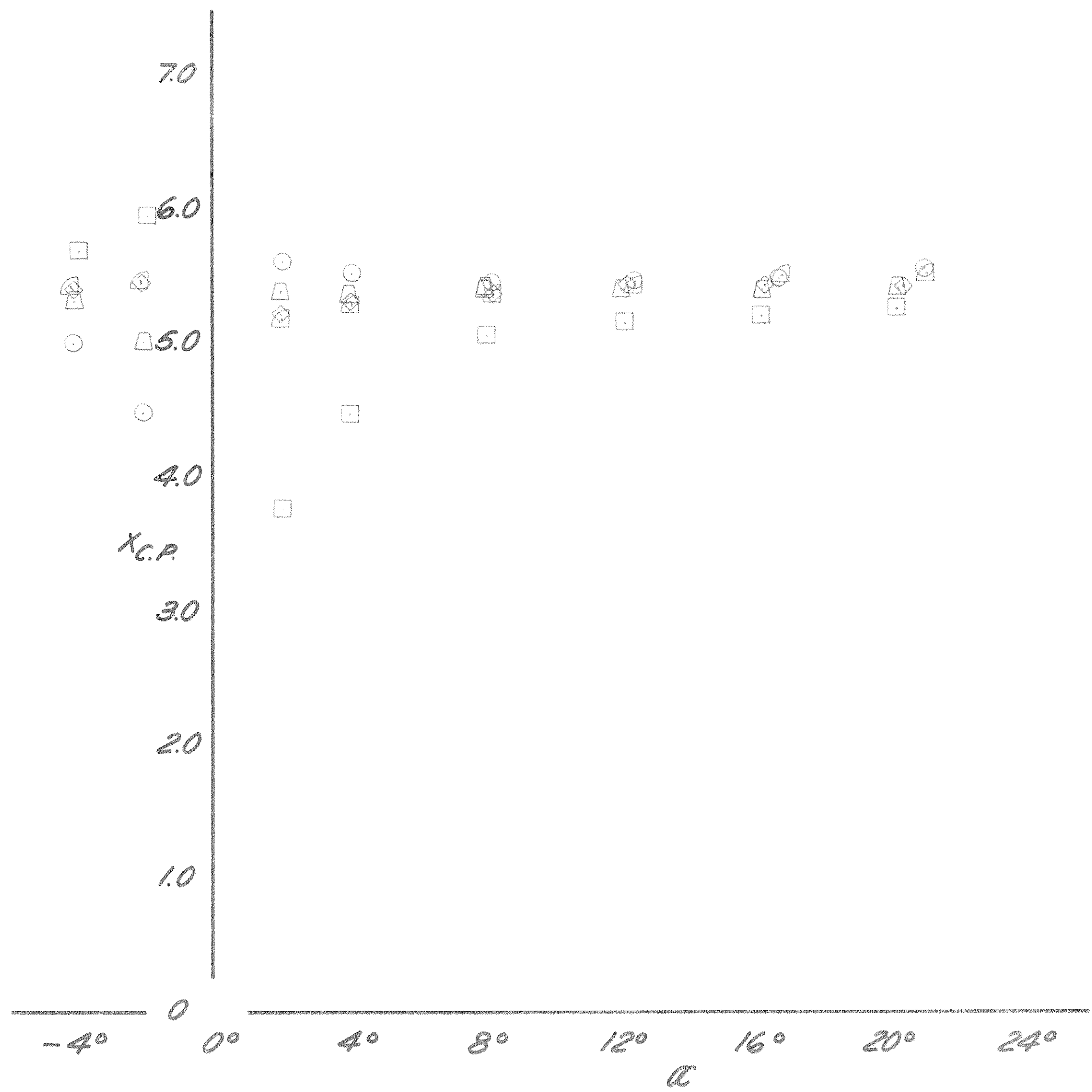
SWT 20-308


CONFIG. 140
GRIT #36 Φ=0°
RUN MACH
⊙ 57 1.32
62 2.01
◇ 51 3.01
△ 46 3.98
⊡ 39 4.76
1.4
1.2
1.0
0.8
Cx
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

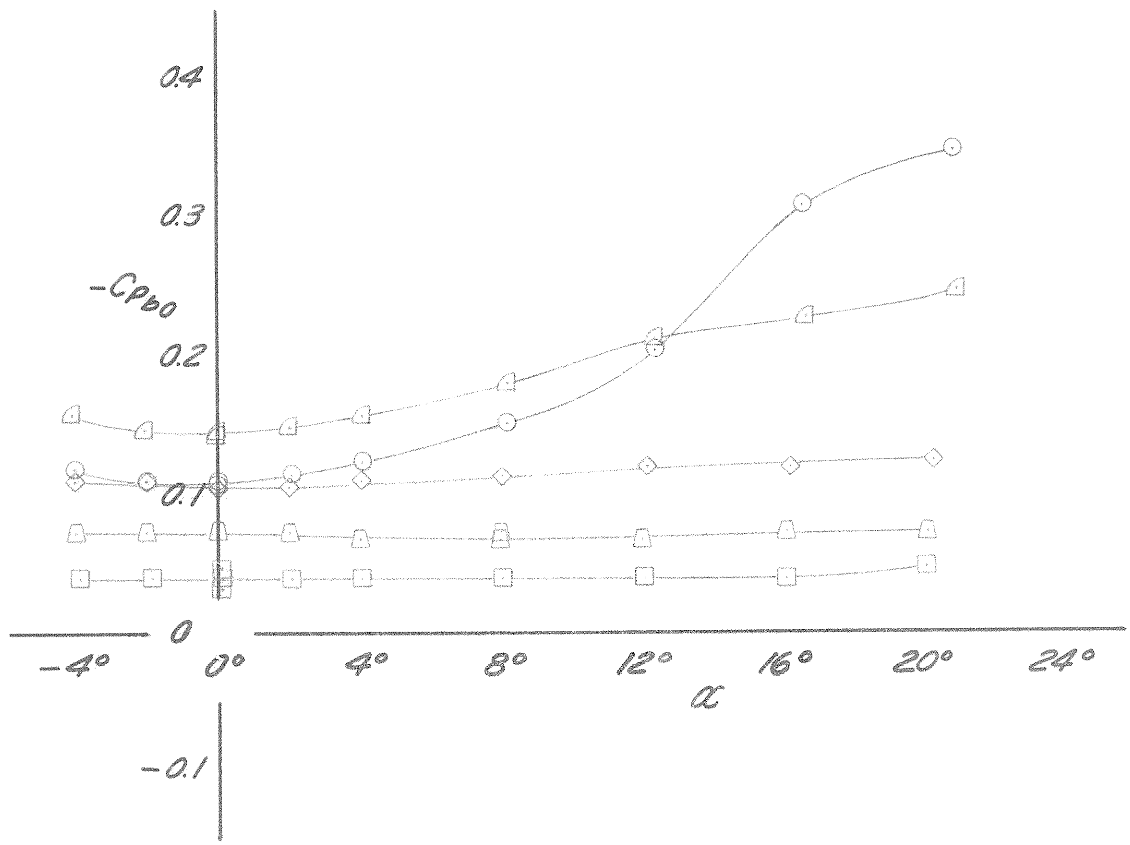
CONFIG. 140
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 57	1.32
62	2.01
◇ 51	3.01
△ 46	3.98
⊡ 39	4.76



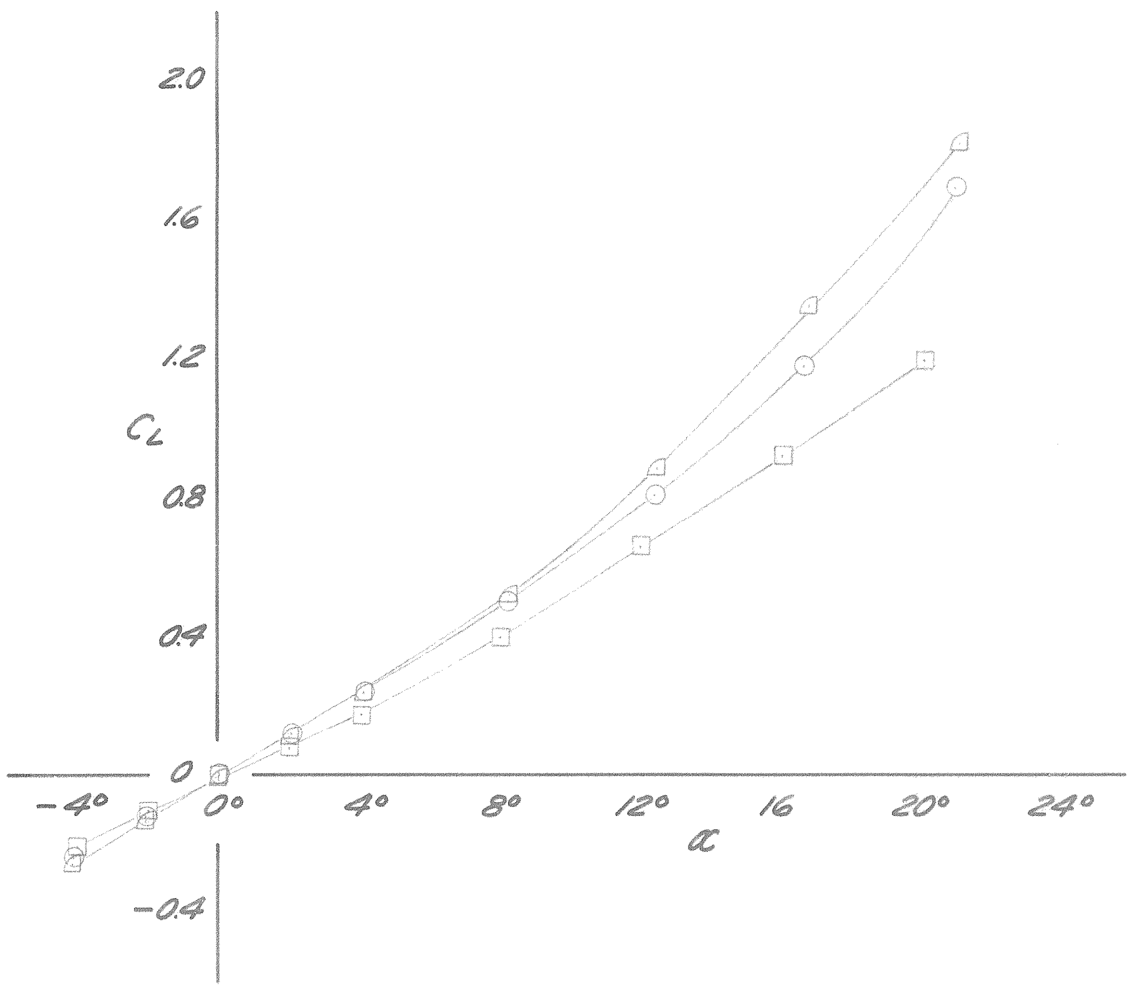
CONFIG. 140
GRIT #36 $\phi = 0°$

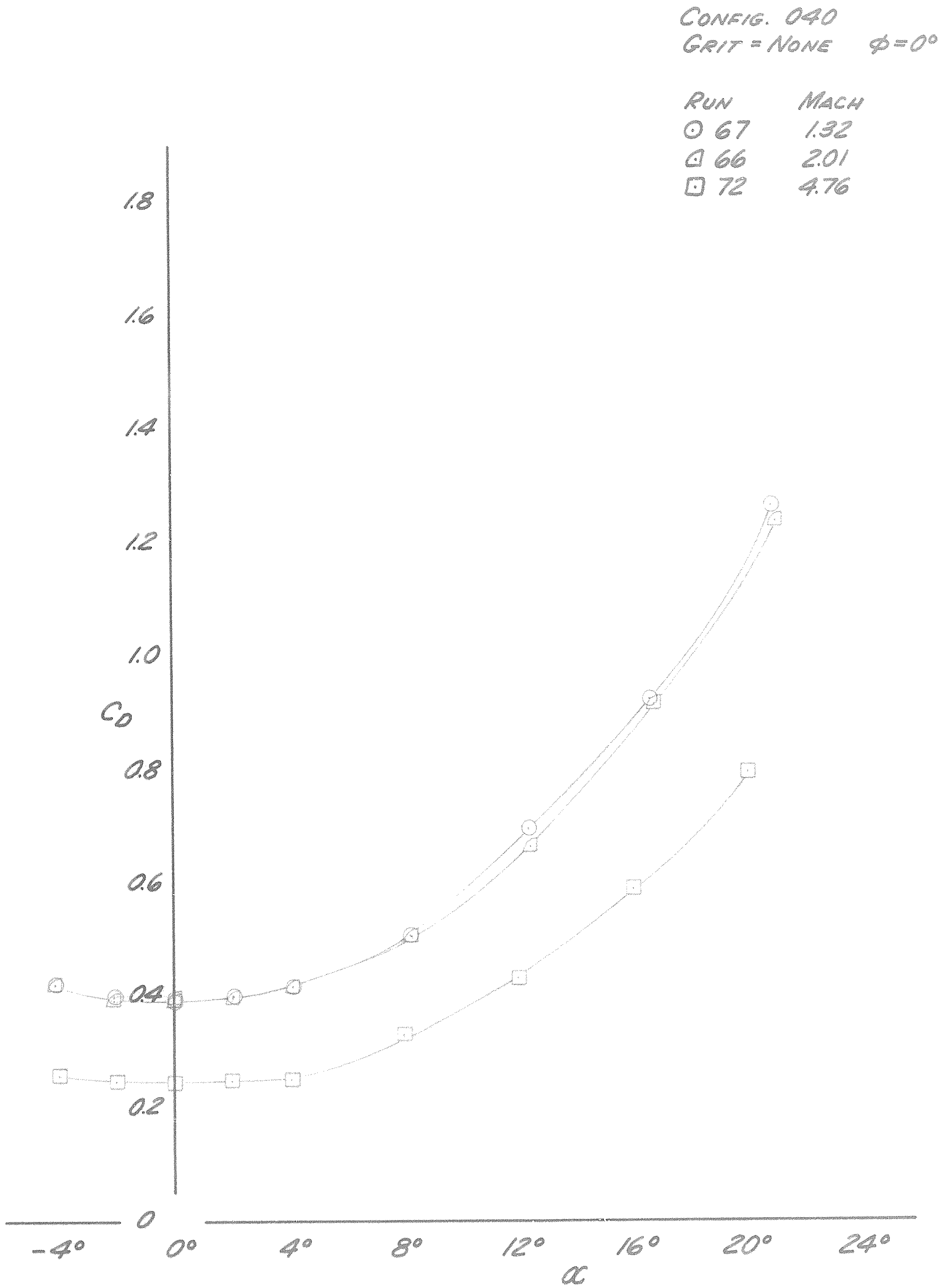
RUN	MACH
⊙ 57	1.32
62	2.01
◇ 51	3.01
△ 46	3.98
⊡ 39	4.76



CONFIG. 040
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 67	1.32
⊿ 66	2.01
⊡ 72	4.76

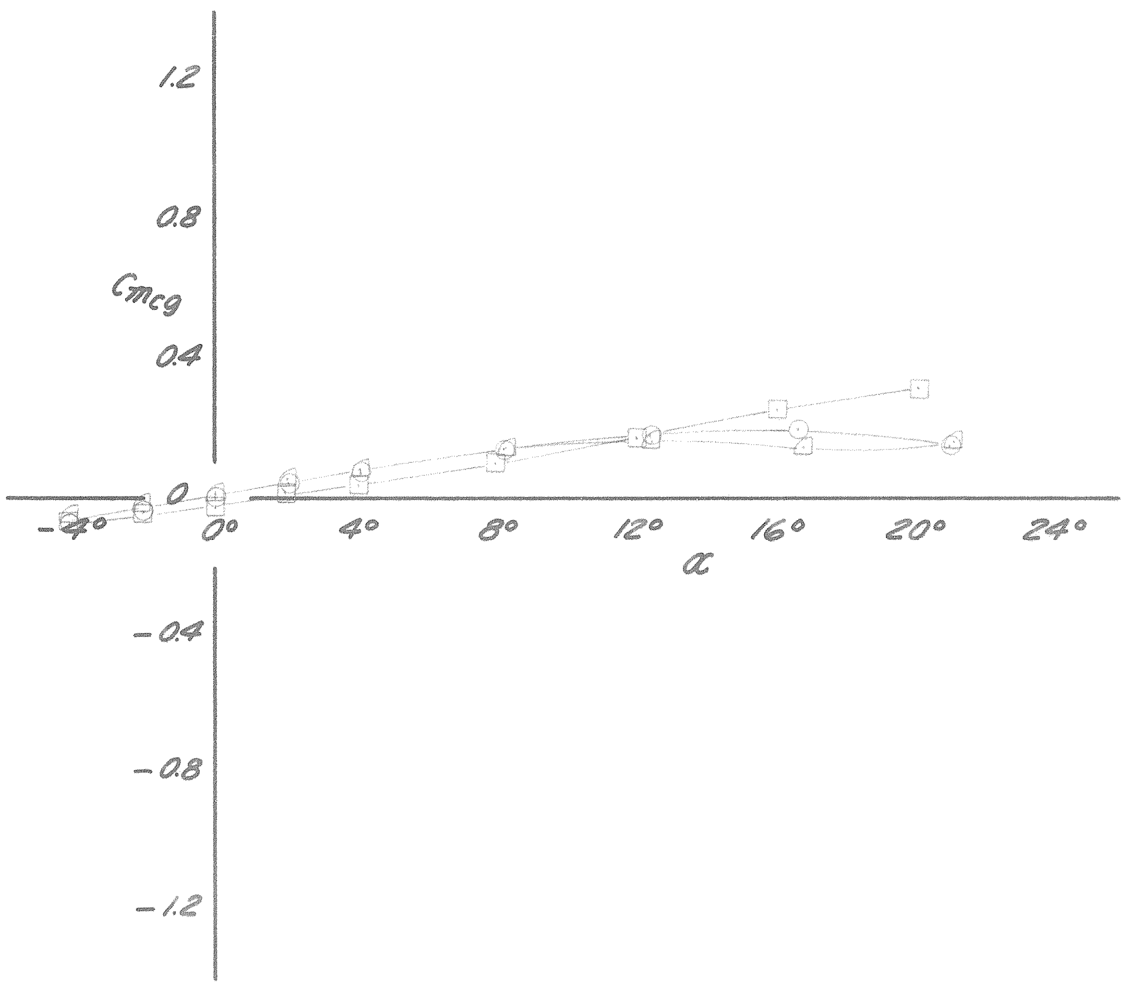



CONFIG. 040
GRIT = NONE $\phi = 0°$
RUN   MACH
67   1.32
66   2.01
72   4.76
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

CONFIG. 040
GRIT = NONE $\phi = 0°$

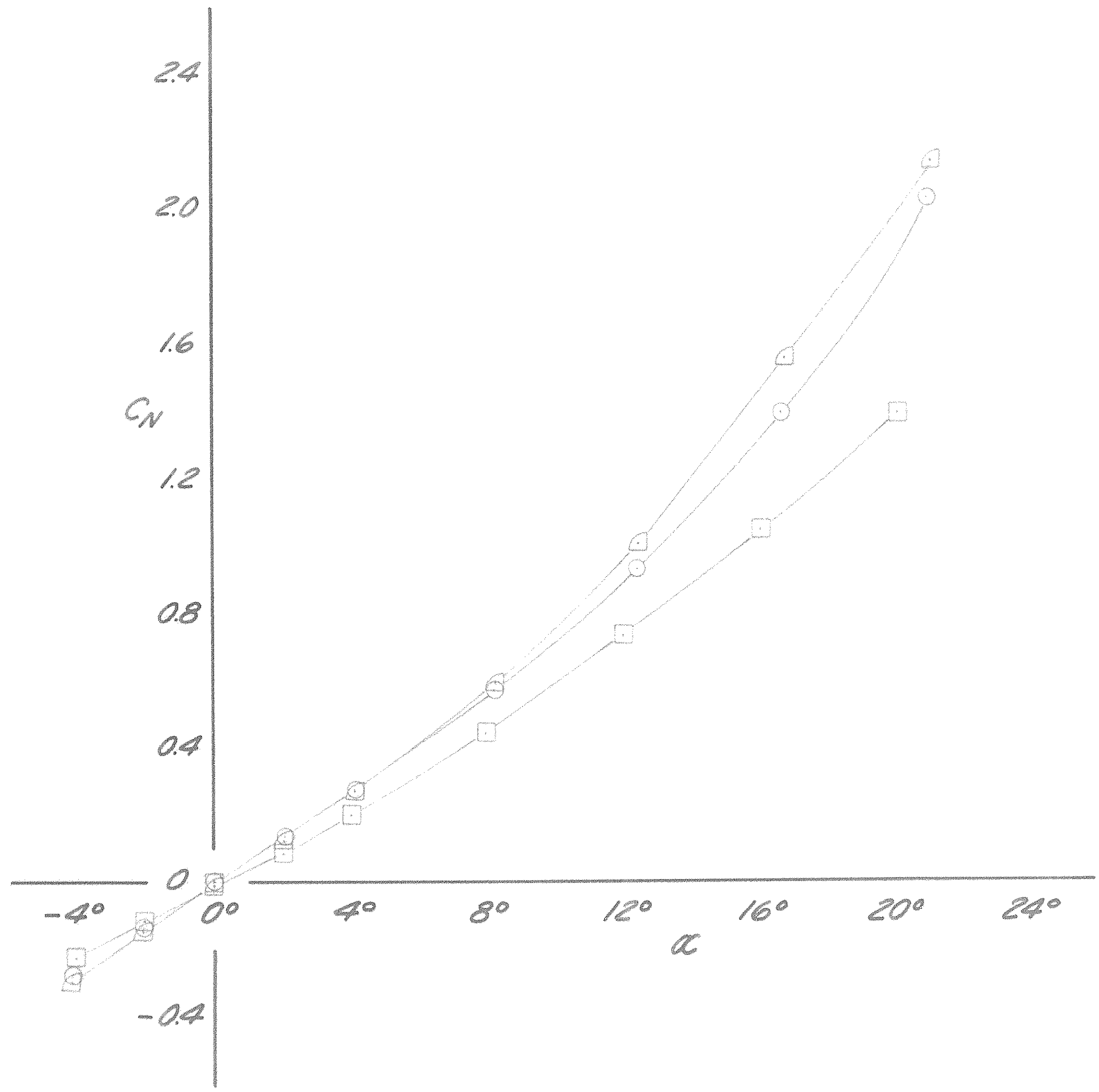
RUN	MACH
⊙ 67	1.32
◿ 66	2.01
⊡ 72	4.76



SWT 20-308

CONFIG. 040
GRIT = NONE $\phi = 0°$

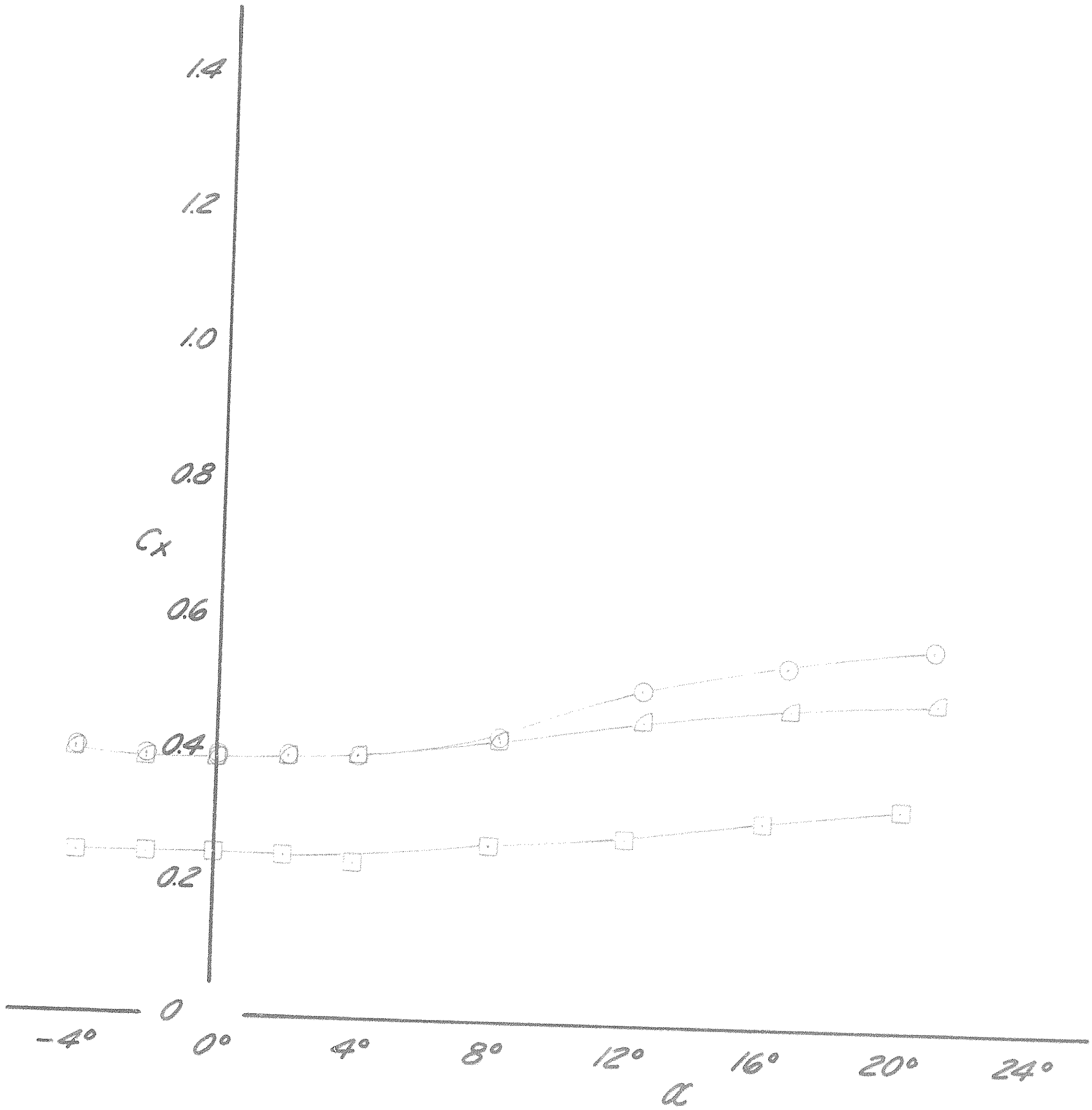
RUN	MACH
⊙ 67	1.32
◇ 66	2.01
⊡ 72	4.76



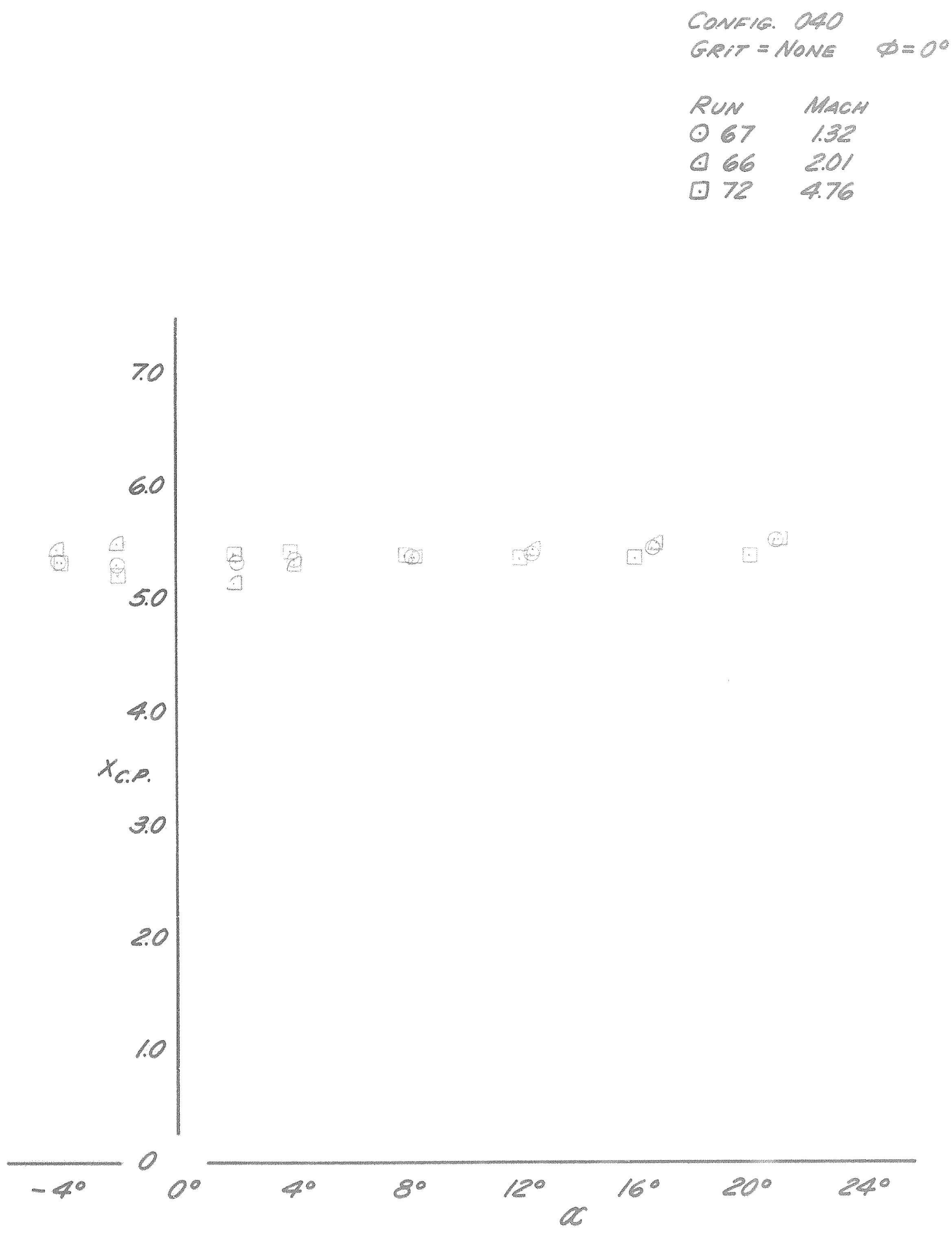
SWT 20-308

CONFIG. 040
GRIT = NONE $\phi = 0°$

RUN	MACH
⊙ 67	1.32
◺ 66	2.01
⊡ 72	4.76

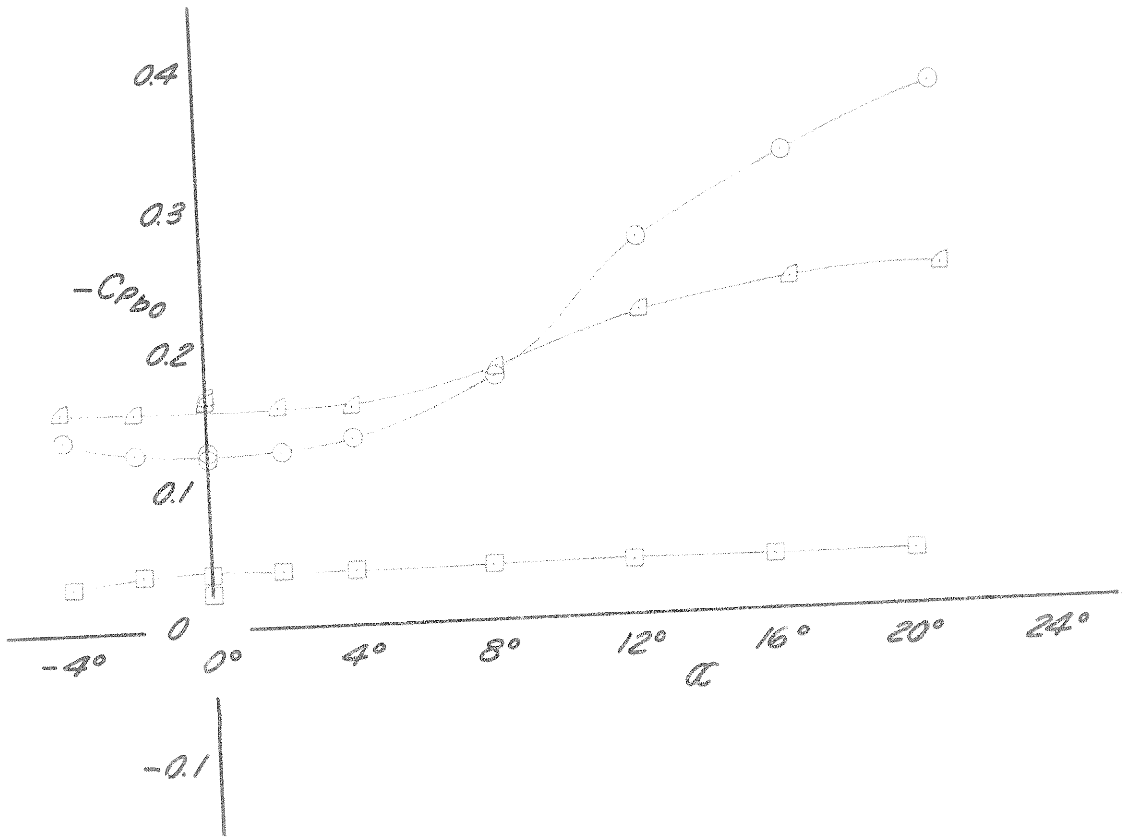


SWT 20-308


CONFIG. 040
GRIT = NONE   Φ = 0°
RUN   MACH
67   1.32
66   2.01
72   4.76
7.0
6.0
5.0
4.0
$X_{C.P.}$
3.0
2.0
1.0
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

CONFIG. 040
GRIT = NONE $\Phi = 0°$

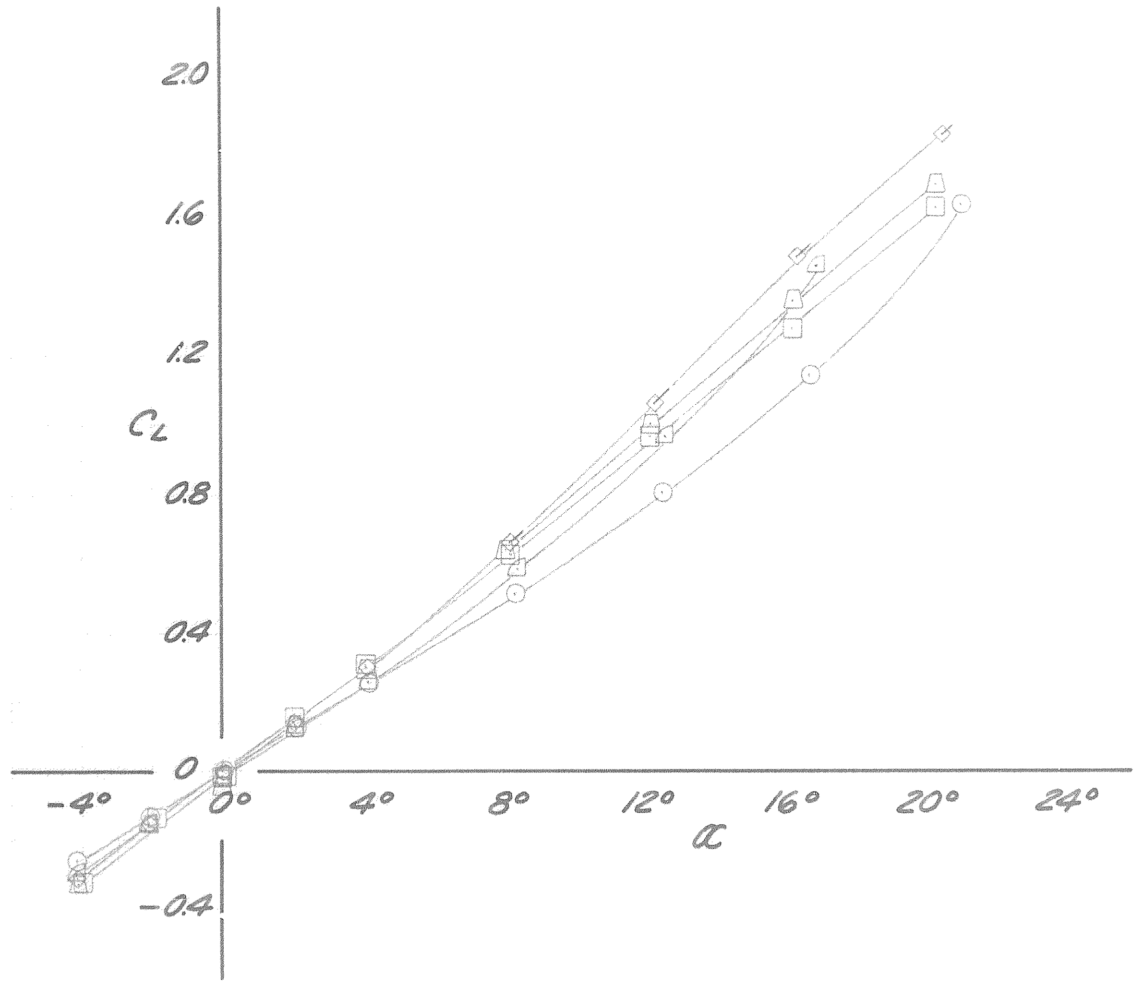
RUN	MACH
⊙ 67	1.32
△ 66	2.01
⊡ 72	4.76

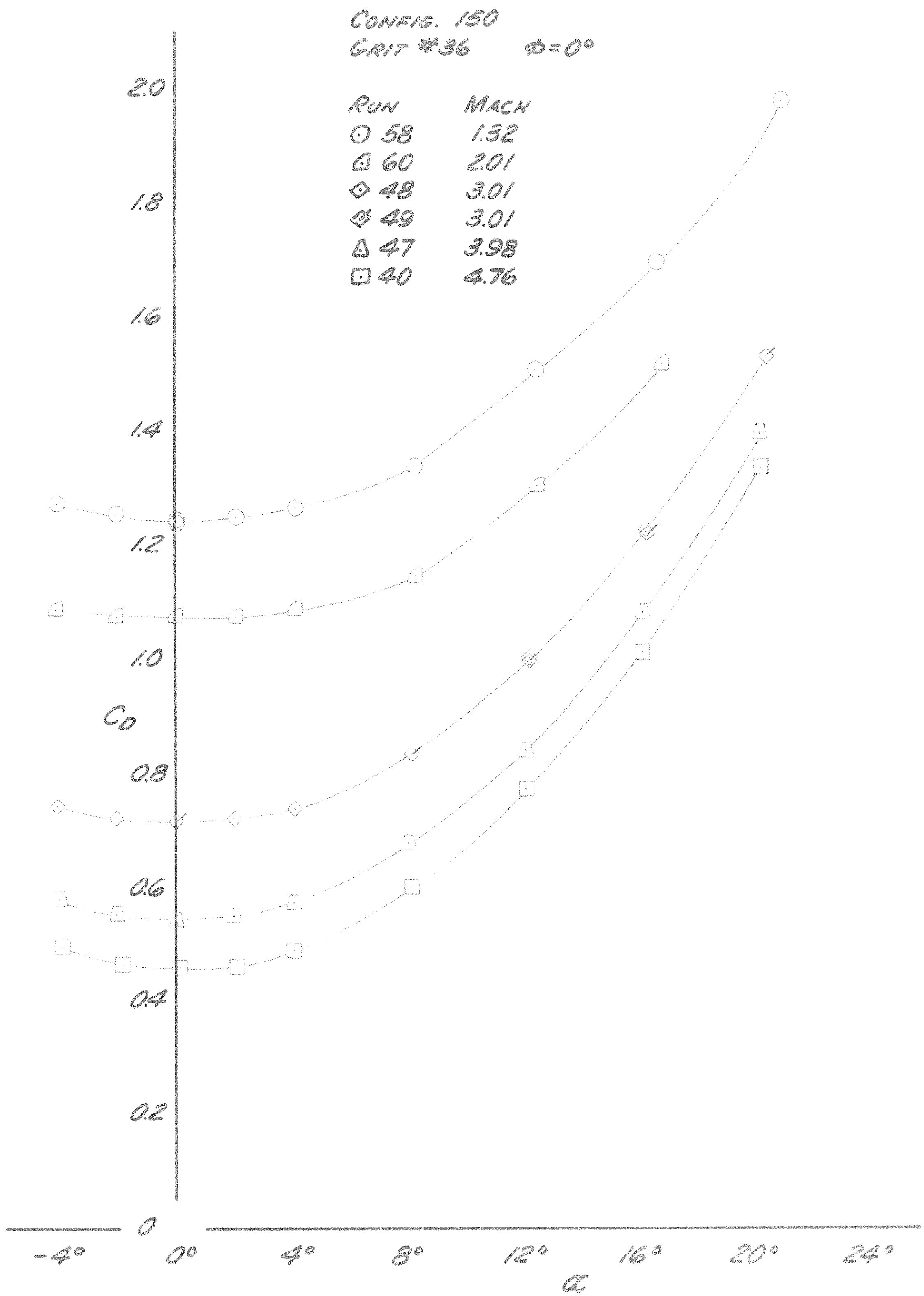


SWT 20-308

CONFIG. 150
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 58	1.32
60	2.01
◇ 48	3.01
49	3.01
△ 47	3.98
⊡ 40	4.76

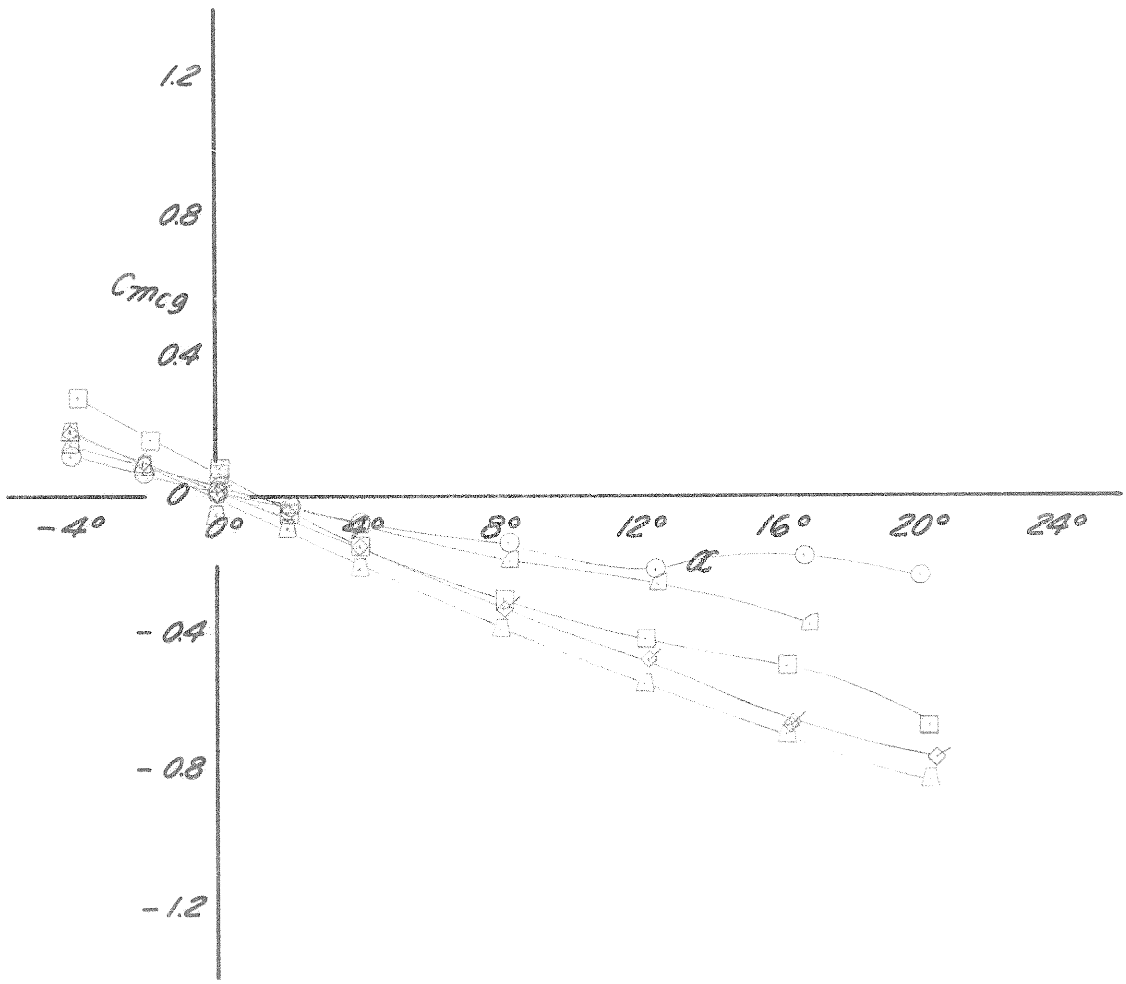



CONFIG. 150
GRIT #36 Φ=0°
RUN MACH
⊙ 58 1.32
60 2.01
◇ 48 3.01
49 3.01
△ 47 3.98
□ 40 4.76
2.0
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

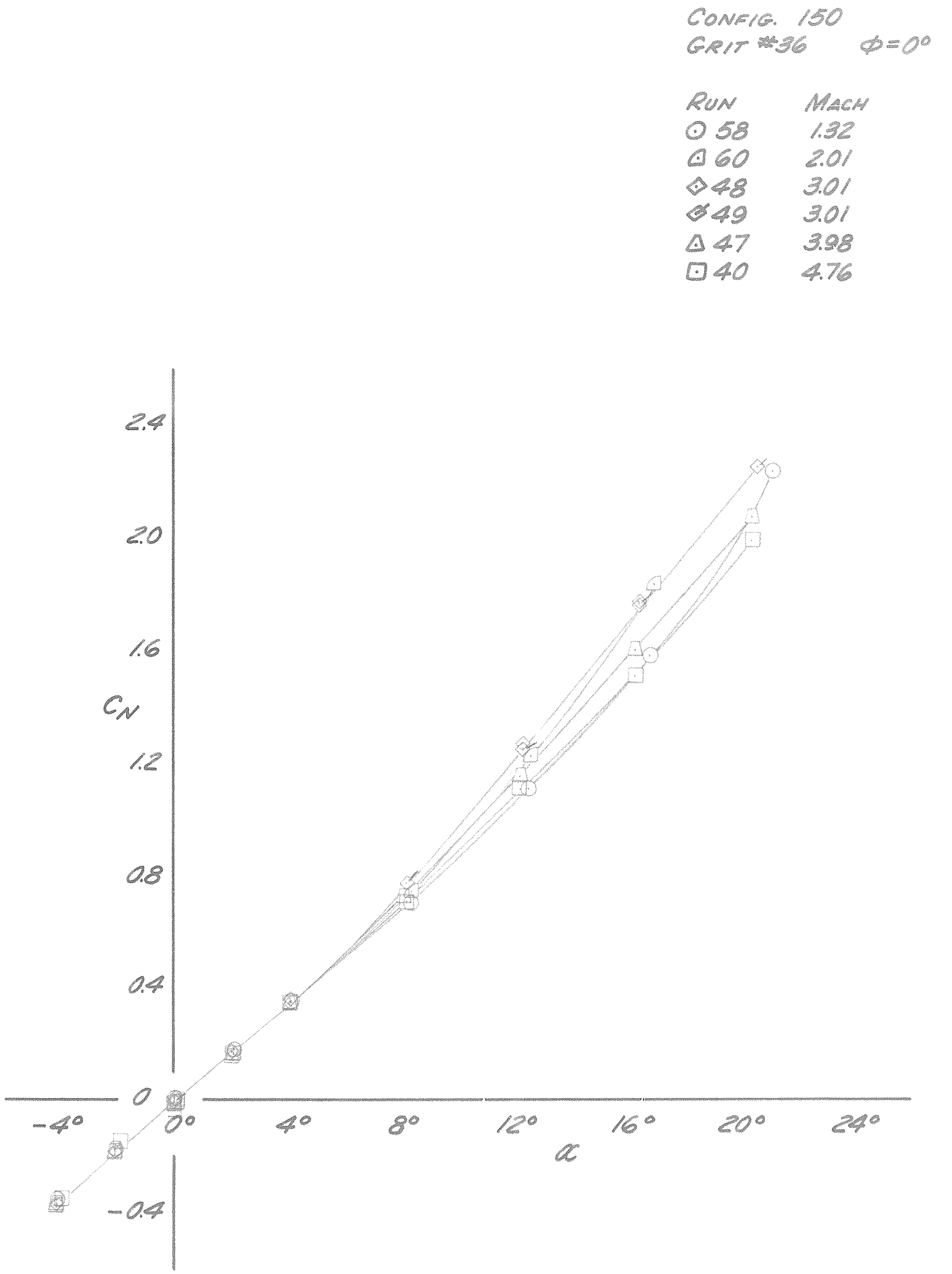
SWT 20-308

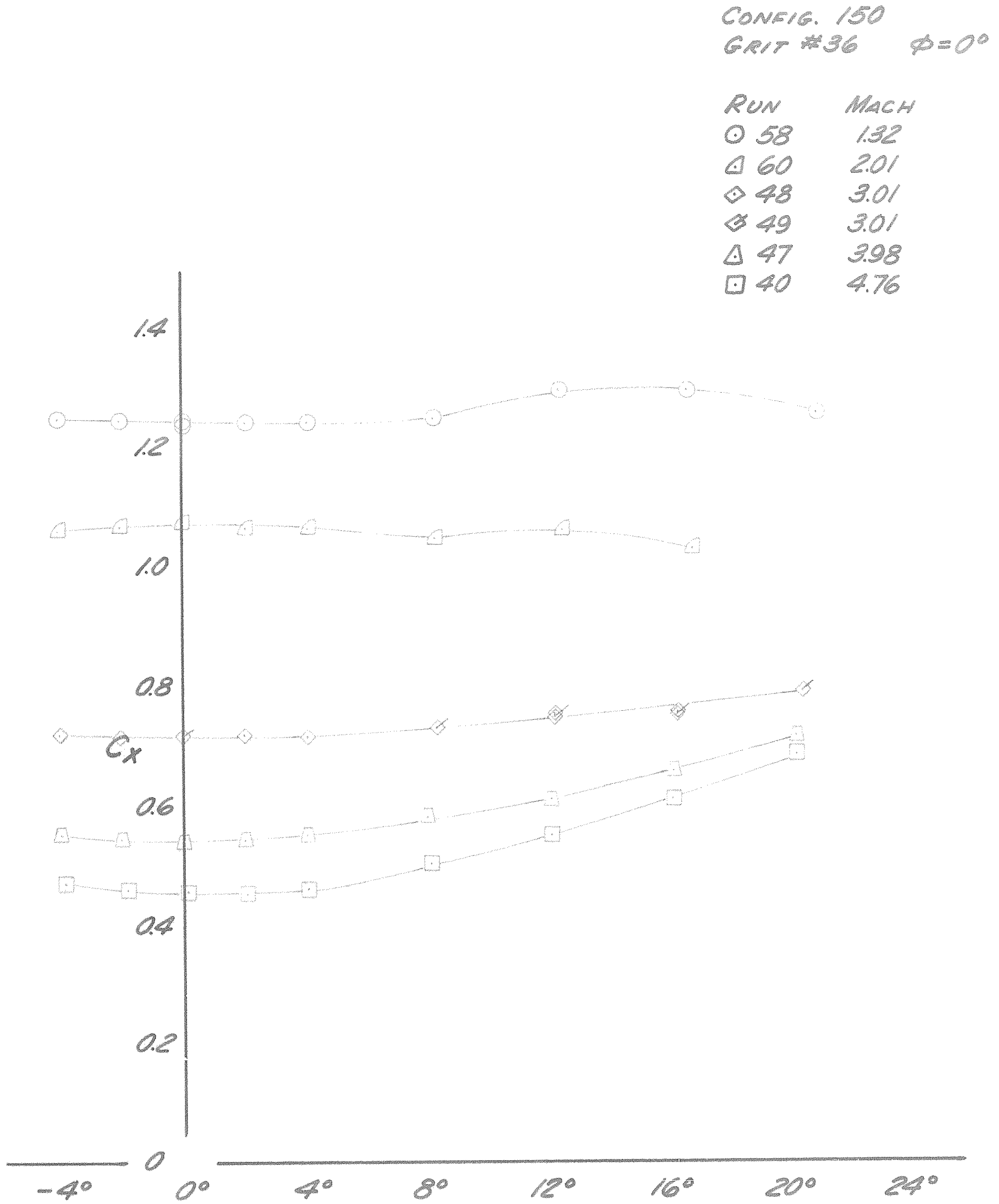
CONFIG. 150
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 58	1.32
60	2.01
◇ 48	3.01
49	3.01
△ 47	3.98
⊡ 40	4.76

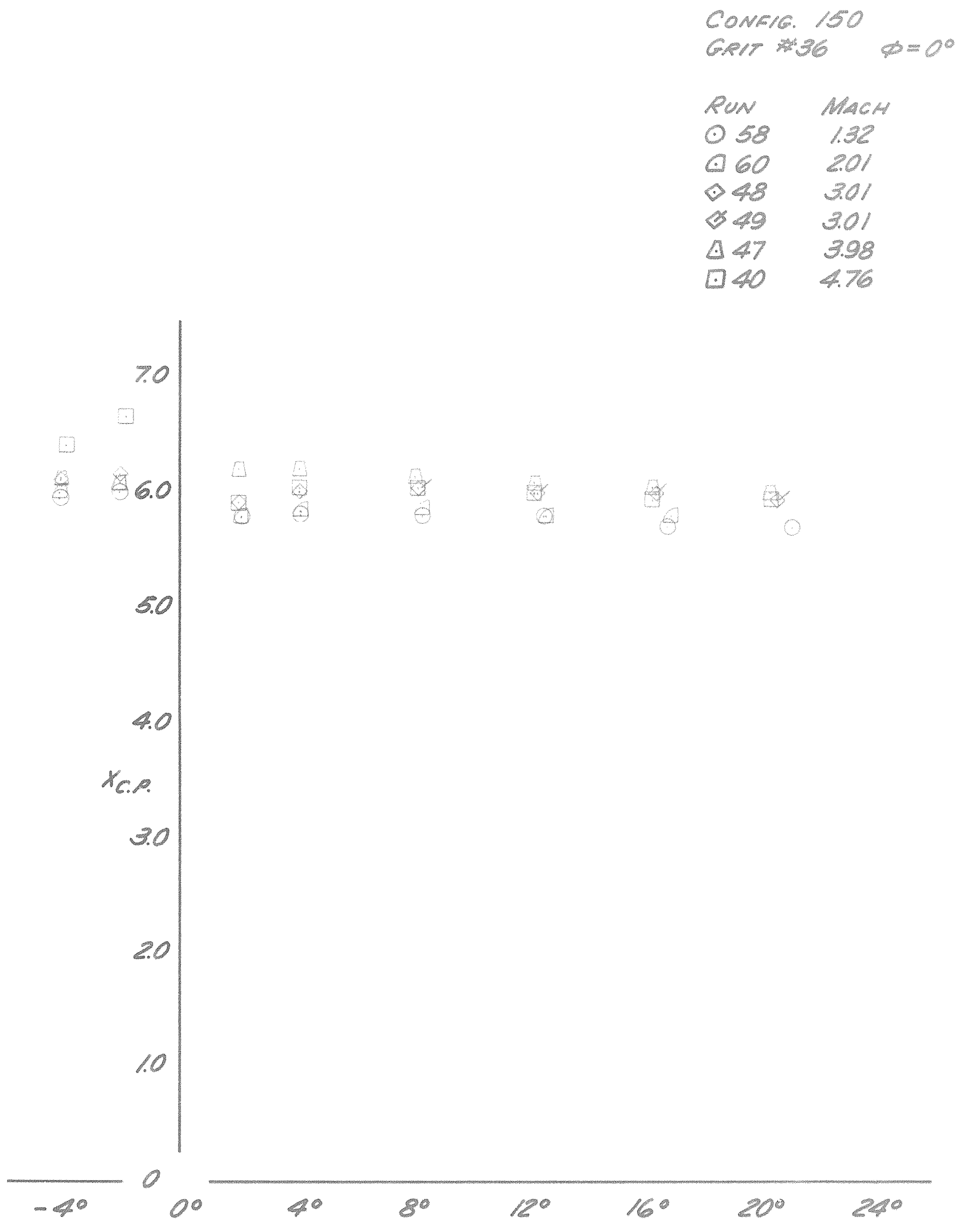


SWT 20-308


CONFIG. 150
GRIT #36 Φ=0°
RUN MACH
⊙ 58 1.32
60 2.01
◇ 48 3.01
49 3.01
△ 47 3.98
□ 40 4.76
2.4
2.0
1.6
1.2
0.8
0.4
0
-0.4
C_N
-4°
0°
4°
8°
12°
16°
20°
24°
α

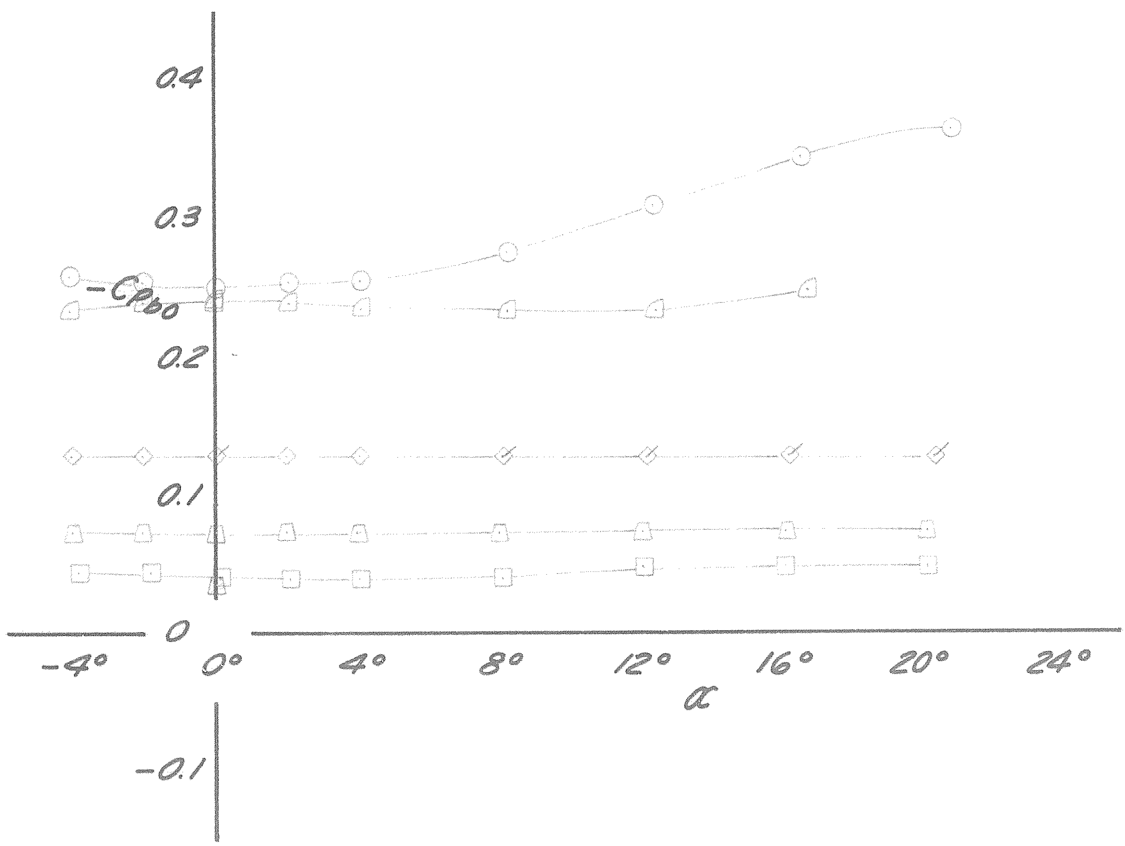

CONFIG. 150
GRIT #36 $\phi = 0°$
RUN MACH
58 1.32
60 2.01
48 3.01
49 3.01
47 3.98
40 4.76
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
C_X
-4°
0°
4°
8°
12°
16°
20°
24°

SWT 20-308


CONFIG. 150
GRIT #36 φ=0°
RUN MACH
58 1.32
60 2.01
48 3.01
49 3.01
47 3.98
40 4.76
7.0
6.0
5.0
4.0
$X_{C.P.}$
3.0
2.0
1.0
0
-4°
0°
4°
8°
12°
16°
20°
24°

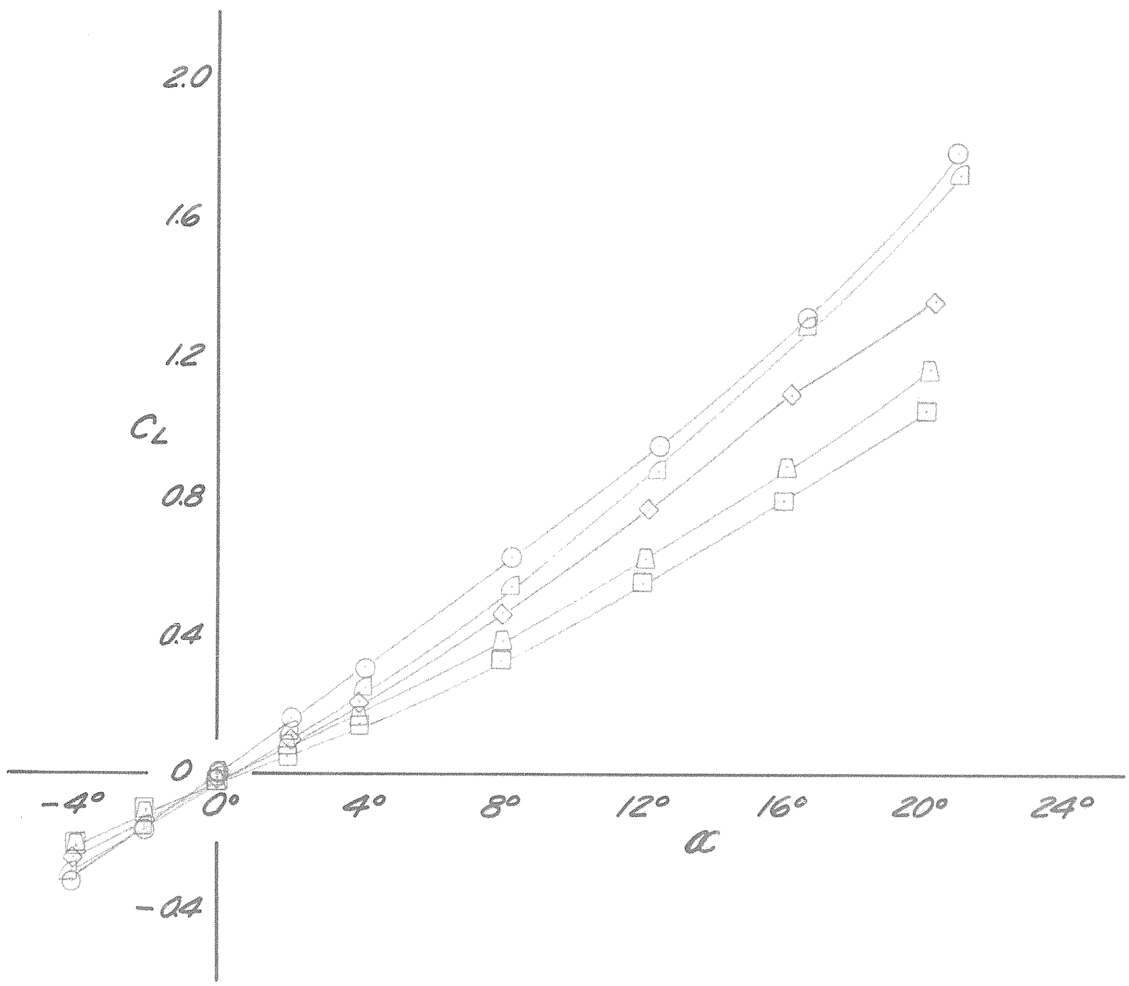
CONFIG. 150
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 58	1.32
60	2.01
◇ 48	3.01
49	3.01
△ 47	3.98
⊡ 40	4.76

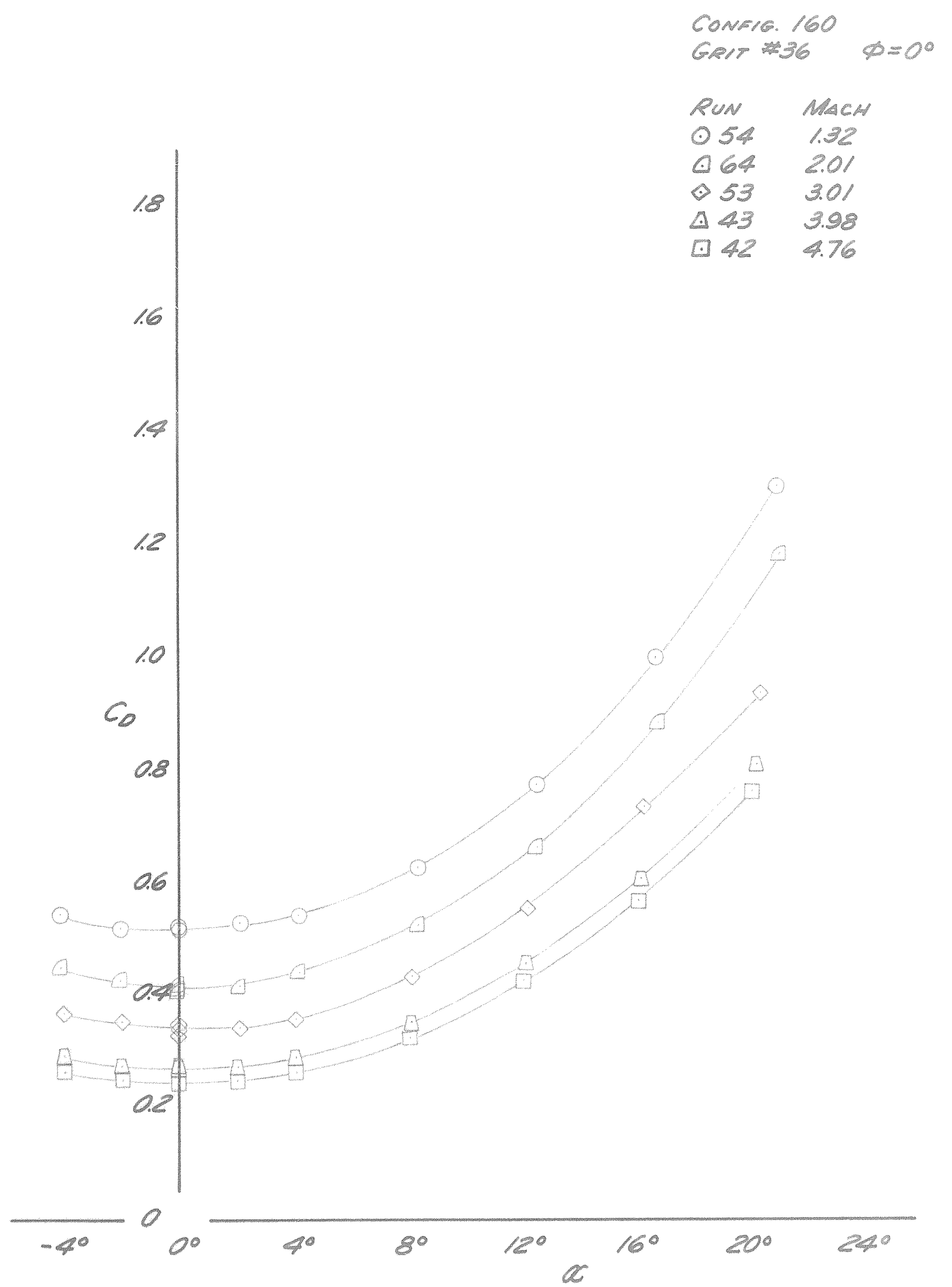


CONFIG. 160
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 54	1.32
64	2.01
◇ 53	3.01
△ 43	3.98
⊡ 42	4.76



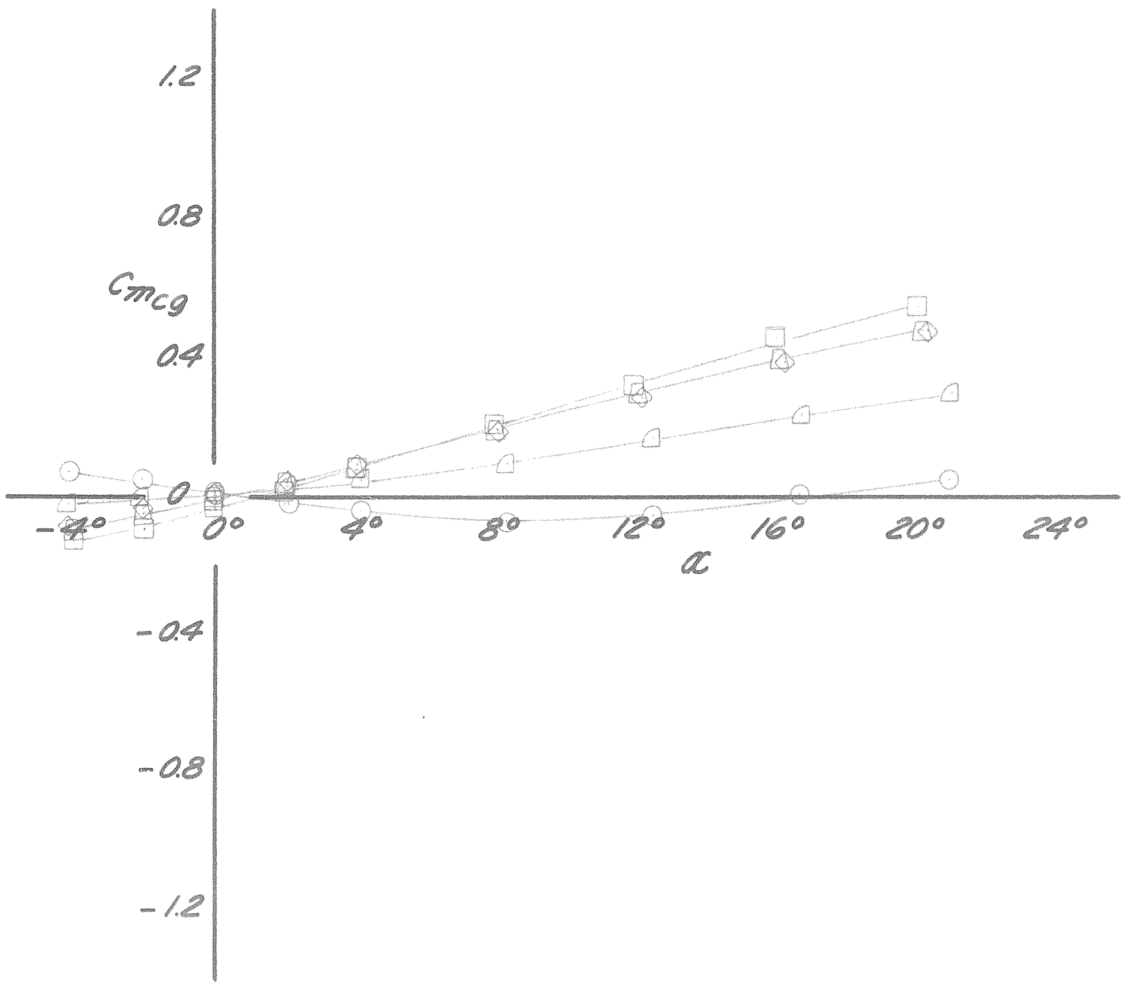
SWT 20-308


CONFIG. 160
GRIT #36 Φ=0°
RUN MACH
54 1.32
64 2.01
53 3.01
43 3.98
42 4.76
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

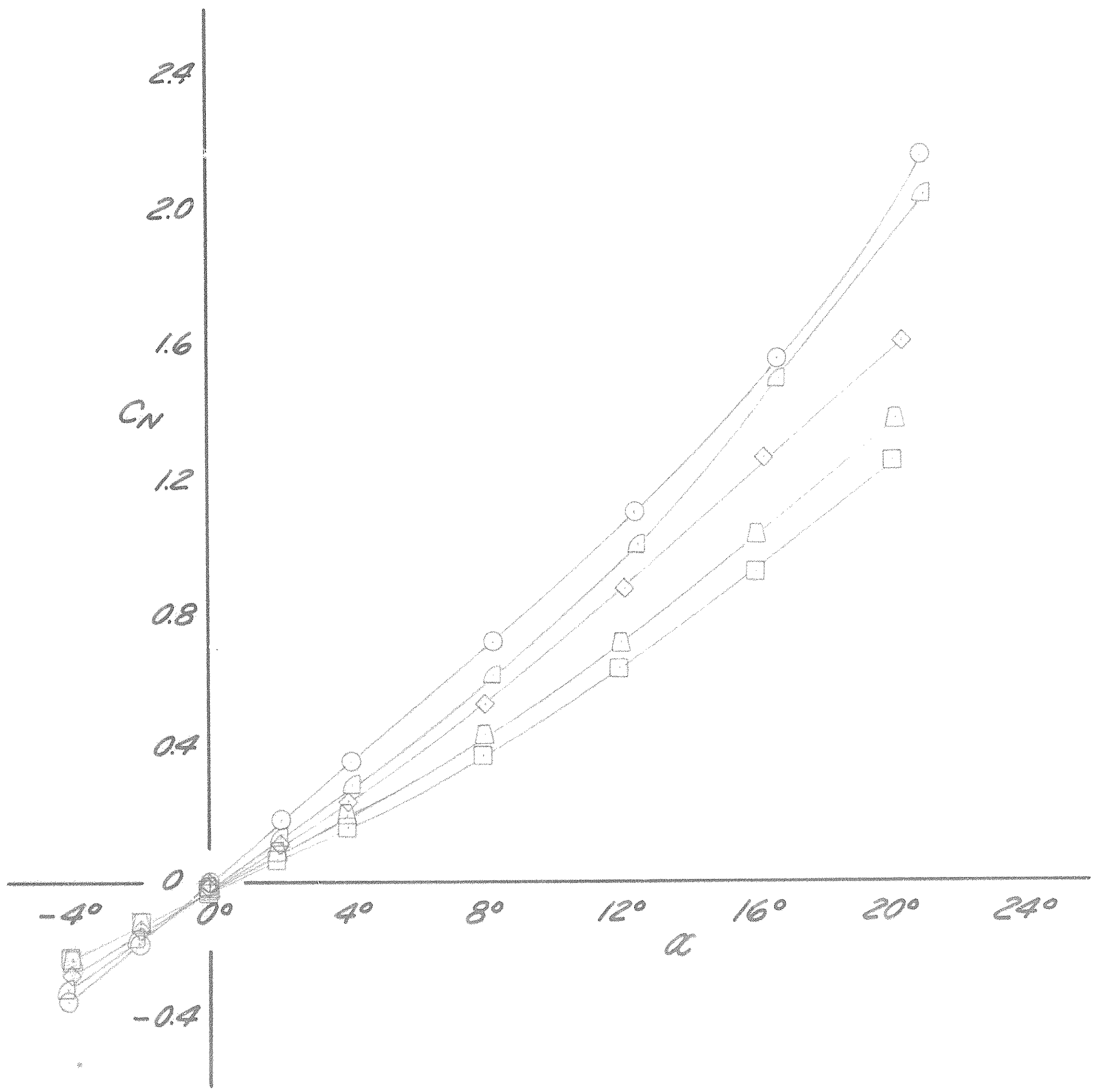
CONFIG. 160
GRIT #36 $\phi = 0°$

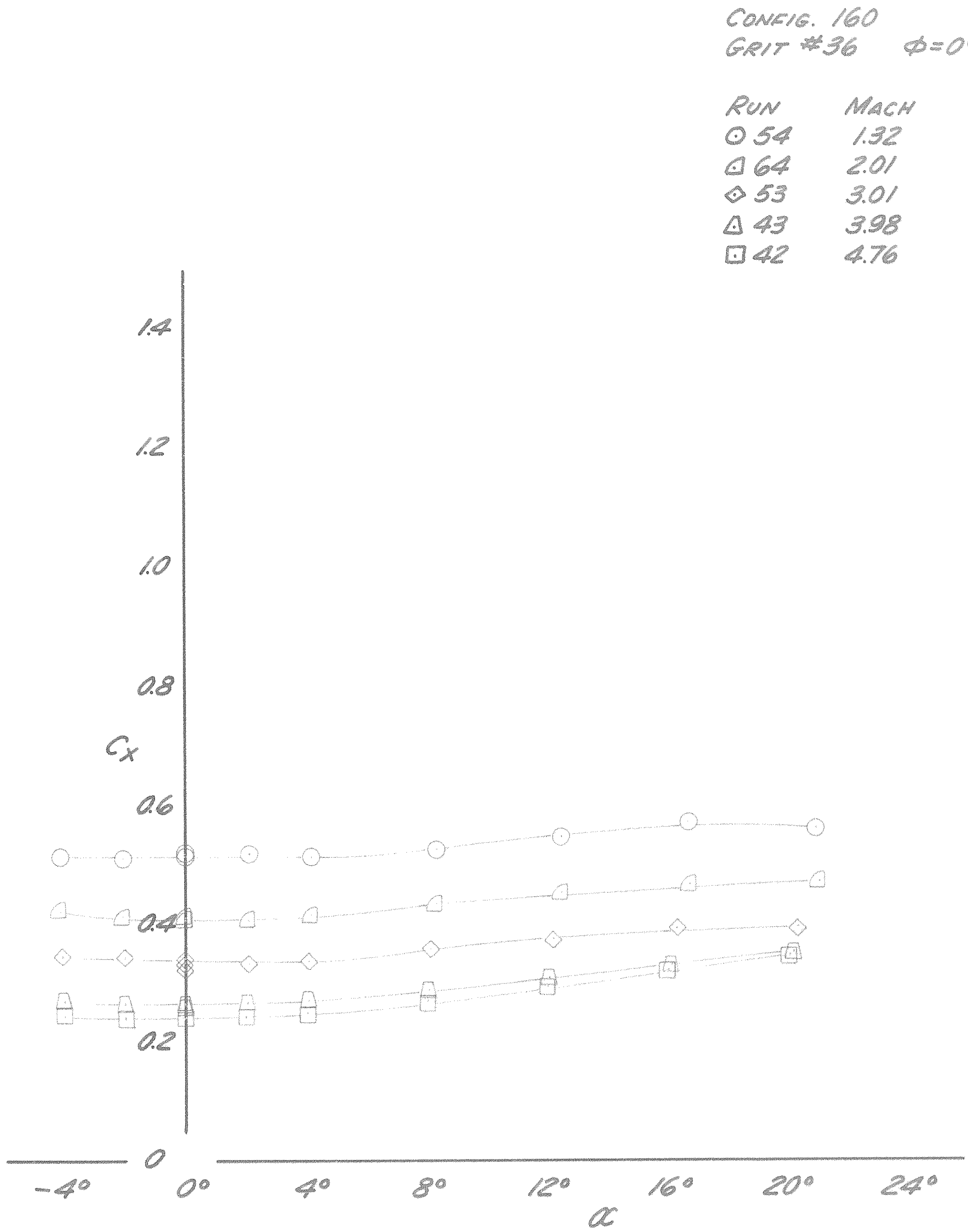
RUN	MACH
⊙ 54	1.32
◺ 64	2.01
◇ 53	3.01
△ 43	3.98
⊡ 42	4.76



CONFIG. 160
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 54	1.32
64	2.01
◇ 53	3.01
△ 43	3.98
⊡ 42	4.76

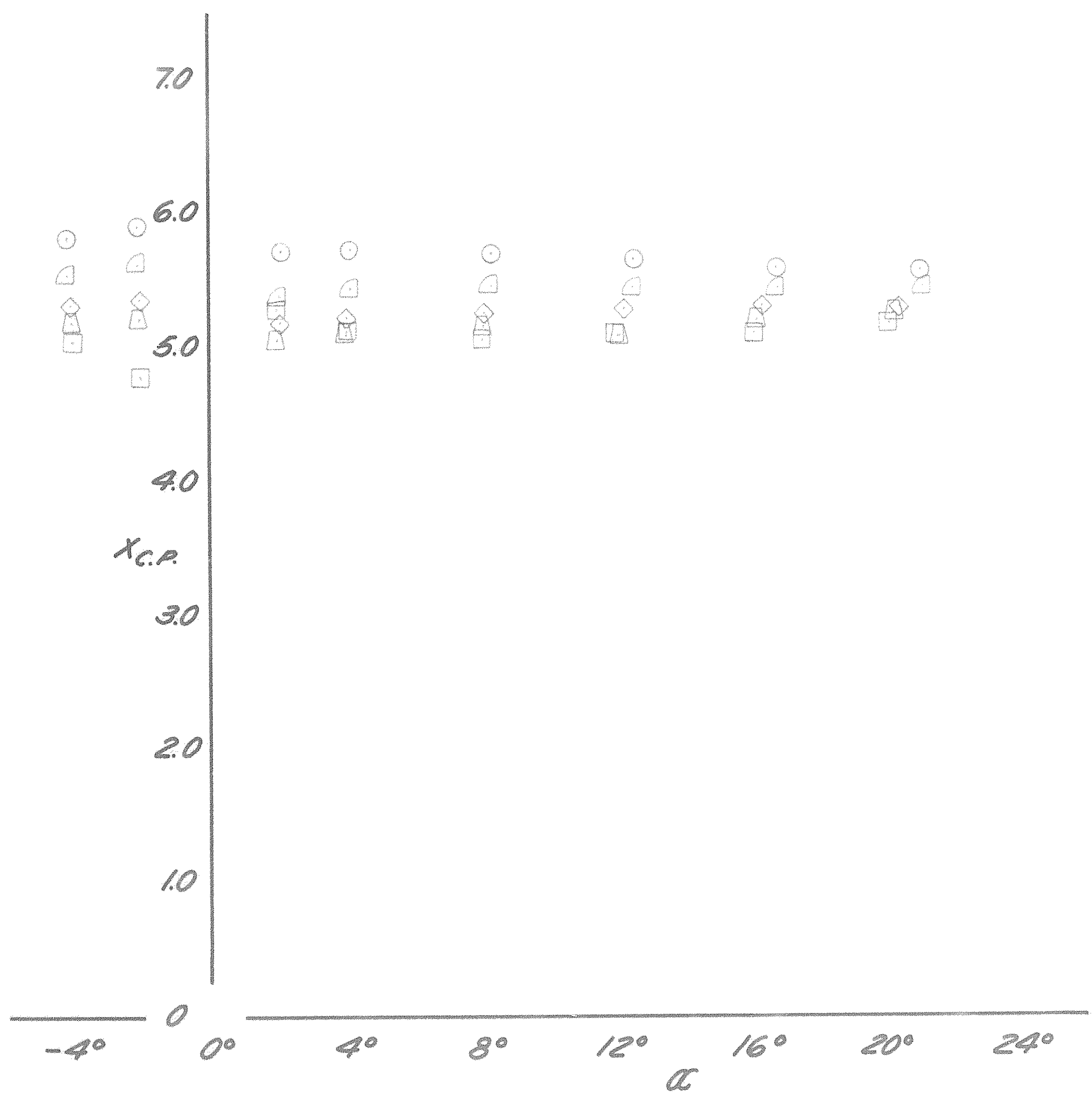



CONFIG. 160
GRIT #36 $\phi=0°$
RUN MACH
54 1.32
64 2.01
53 3.01
43 3.98
42 4.76
1.4
1.2
1.0
0.8
C_X
0.6
0.4
0.2
0
−4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

CONFIG. 160
GRIT #36 $\phi = 0°$

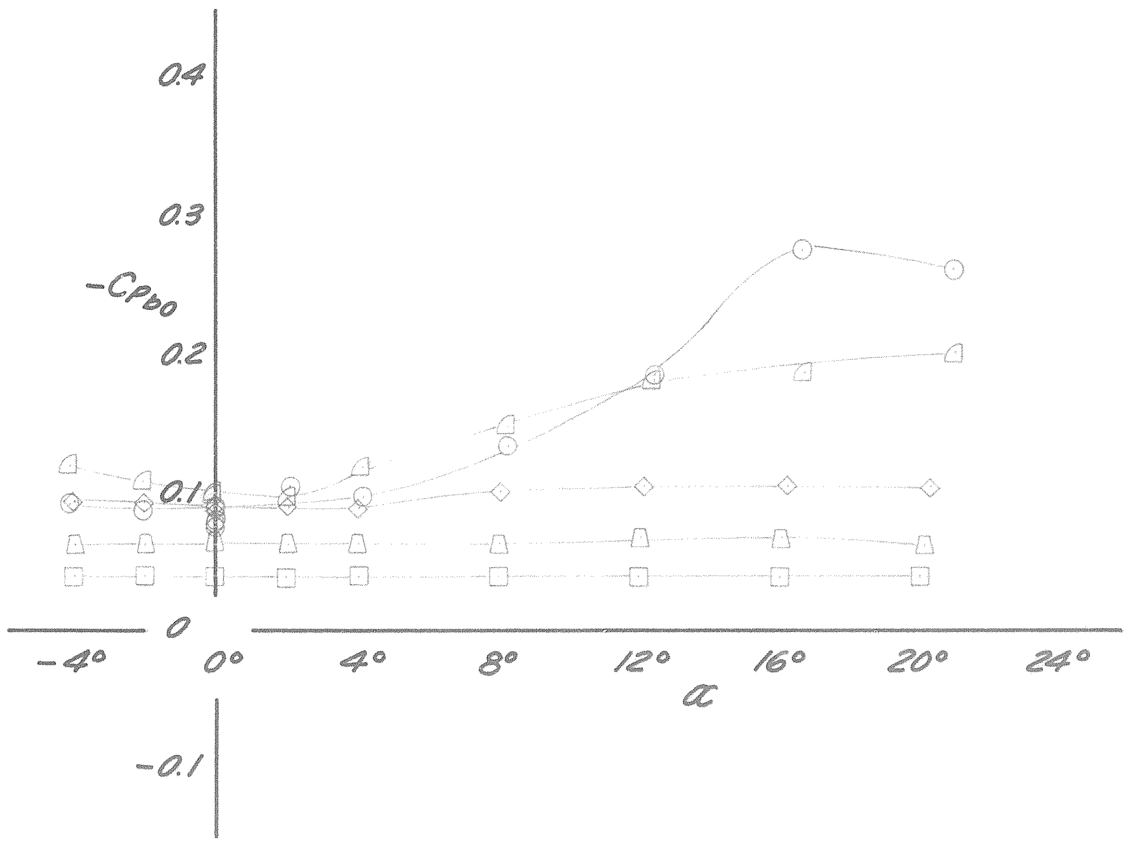
RUN	MACH
⊙ 54	1.32
◺ 64	2.01
◇ 53	3.01
△ 43	3.98
⊡ 42	4.76



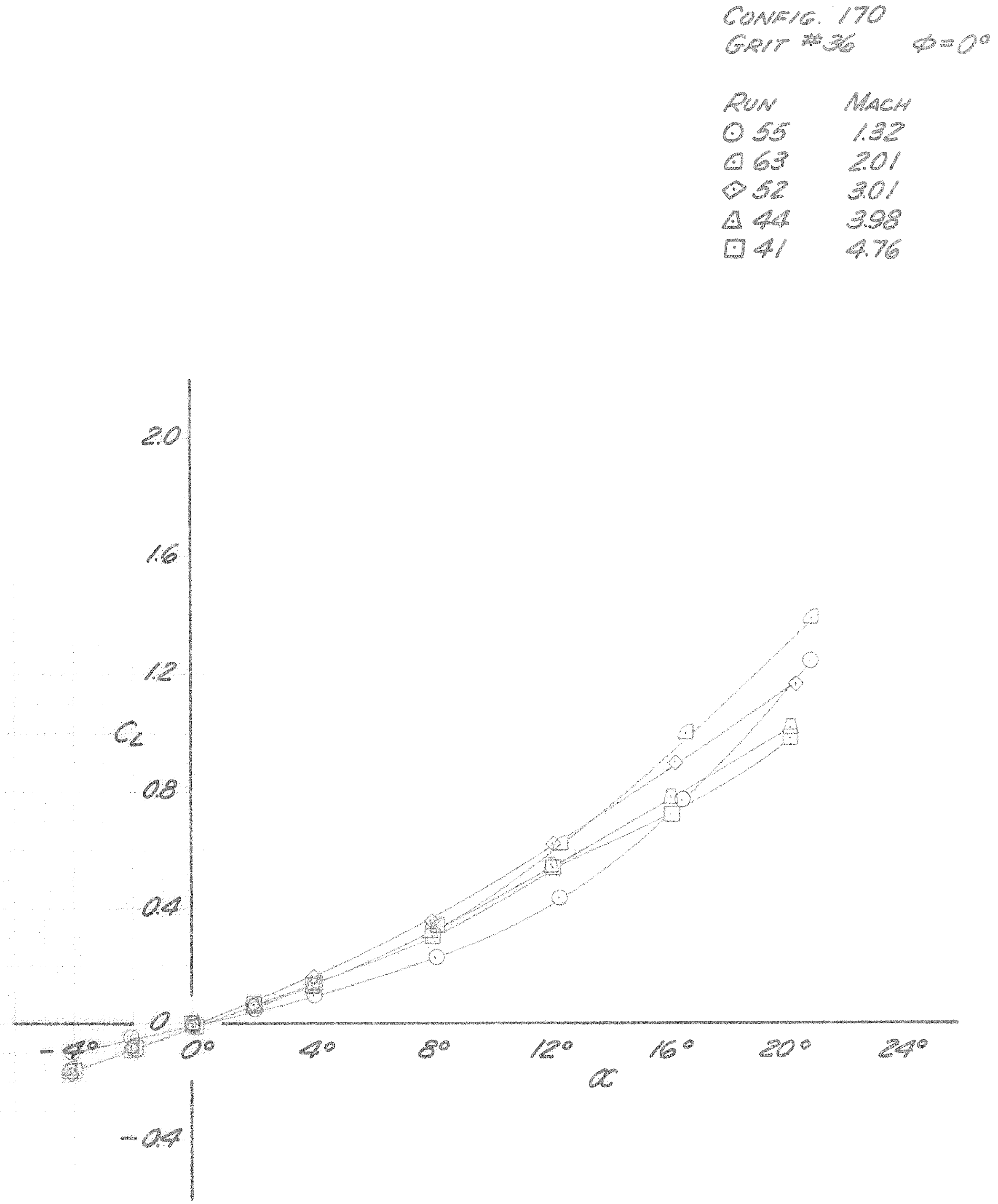
SWT 20-308

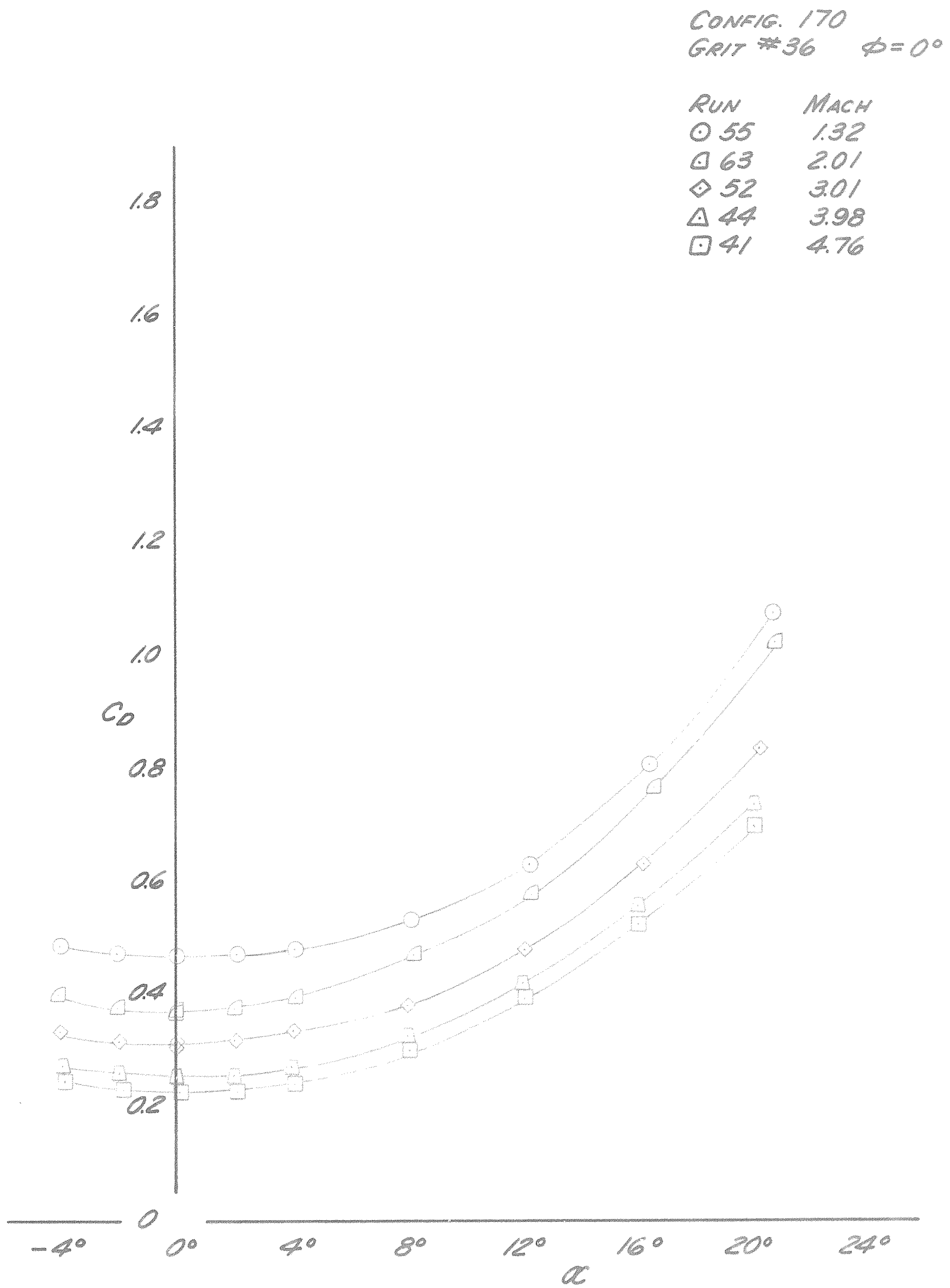
CONFIG. 160
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 54	1.32
64	2.01
◇ 53	3.01
△ 43	3.98
⊡ 42	4.76



SWT 20-308

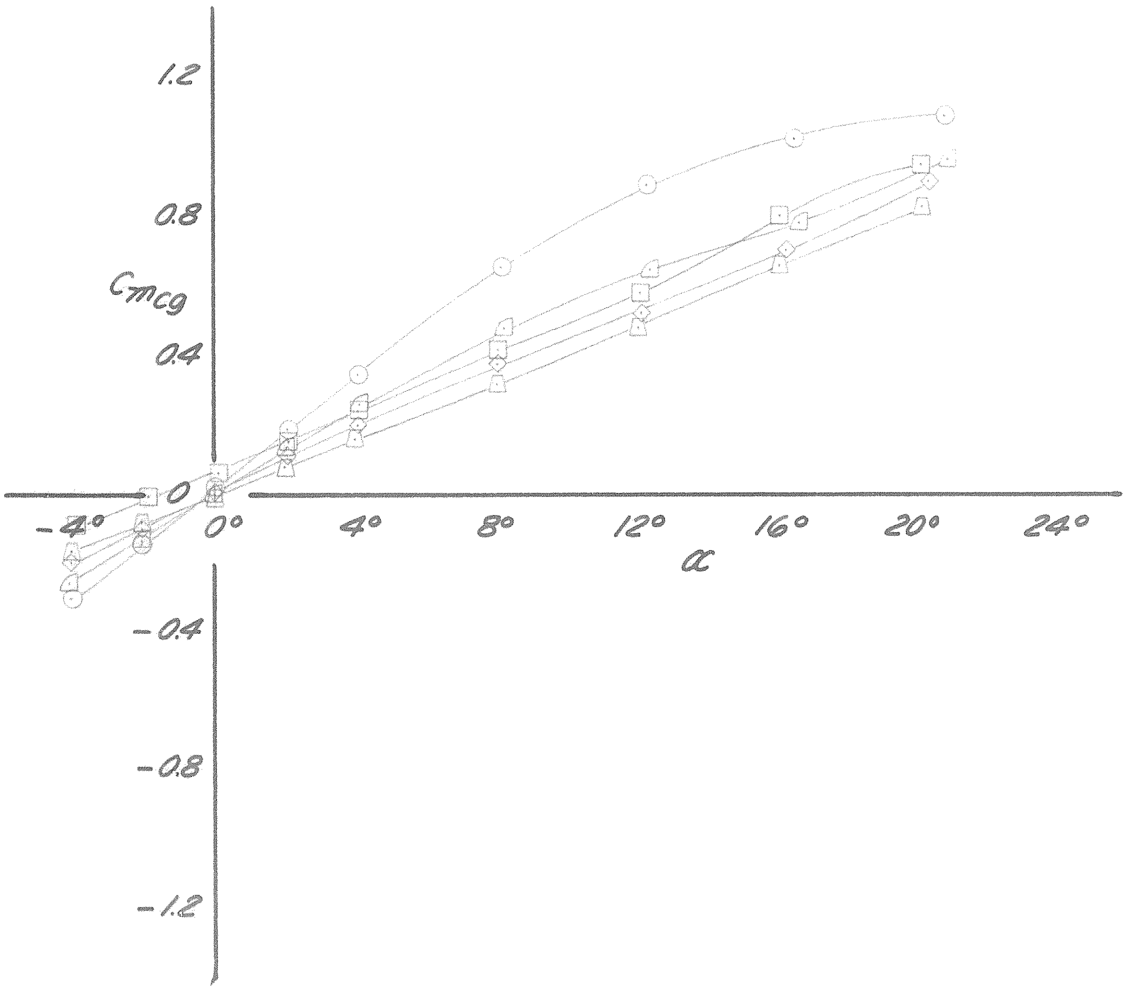

CONFIG. 170
GRIT #36 Φ=0°
RUN MACH
55 1.32
63 2.01
52 3.01
44 3.98
41 4.76
2.0
1.6
1.2
C_L
0.8
0.4
0
-0.4
-4°
0°
4°
8°
12°
16°
20°
24°
α


CONFIG. 170
GRIT #36 $\phi = 0°$
RUN MACH
55 1.32
63 2.01
52 3.01
44 3.98
41 4.76
1.8
1.6
1.4
1.2
1.0
C_D
0.8
0.6
0.4
0.2
0
−4°
0°
4°
8°
12°
16°
20°
24°
α

SWT 20-308

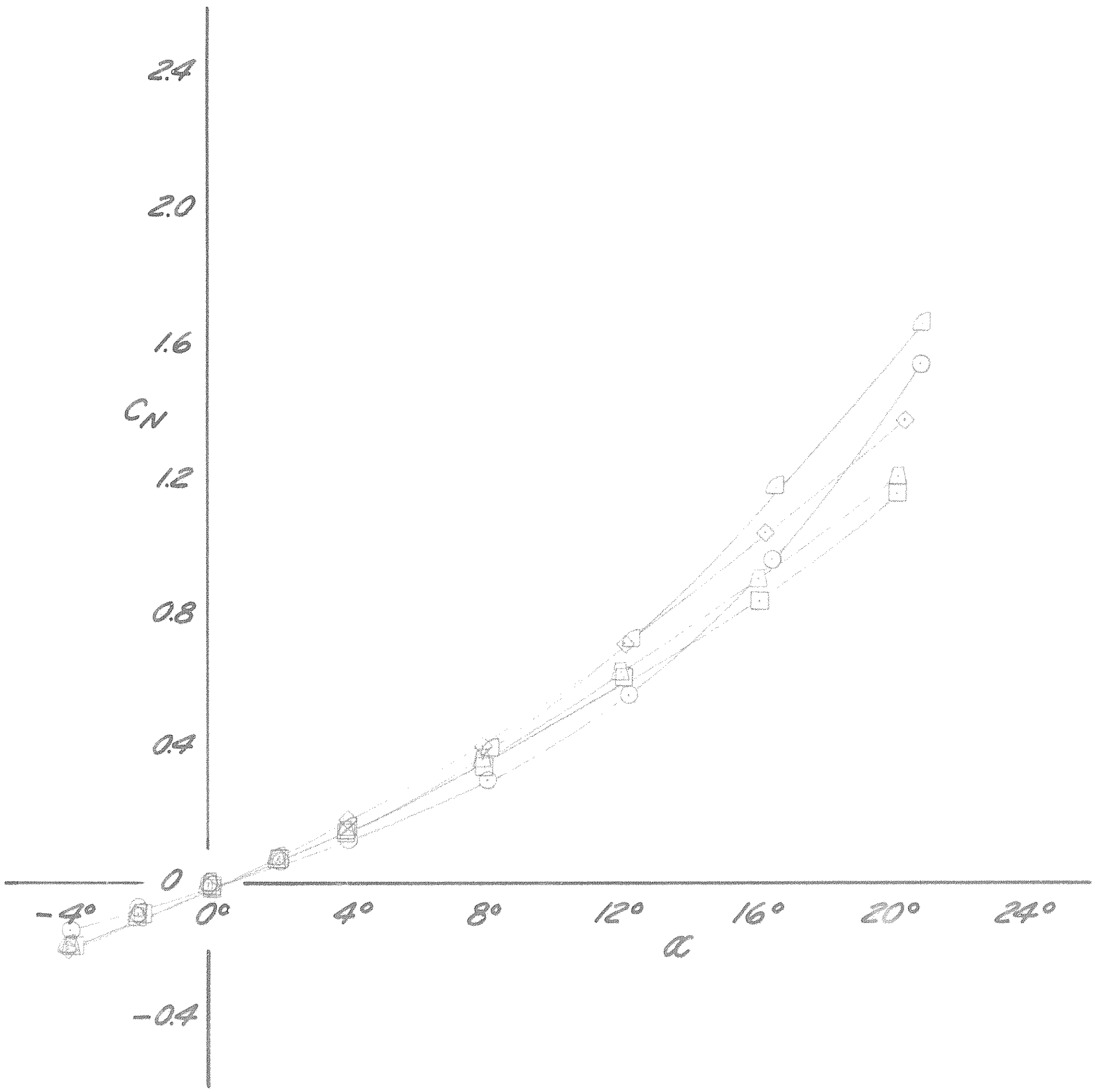
CONFIG. 170
GRIT #36 $\phi = 0°$

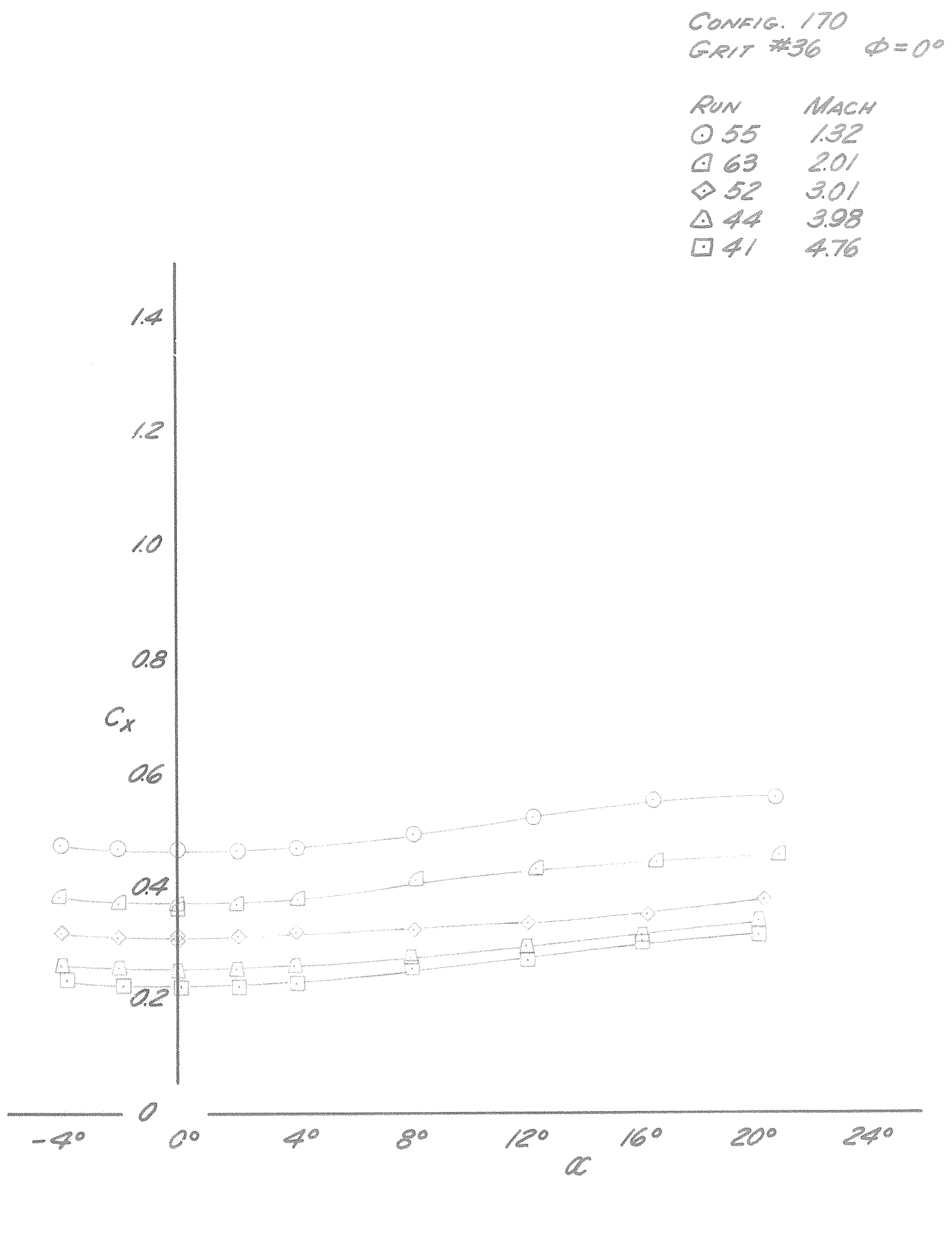
RUN	MACH
⊙ 55	1.32
63	2.01
◇ 52	3.01
△ 44	3.98
□ 41	4.76



CONFIG. 170
GRIT #36 $\phi = 0°$

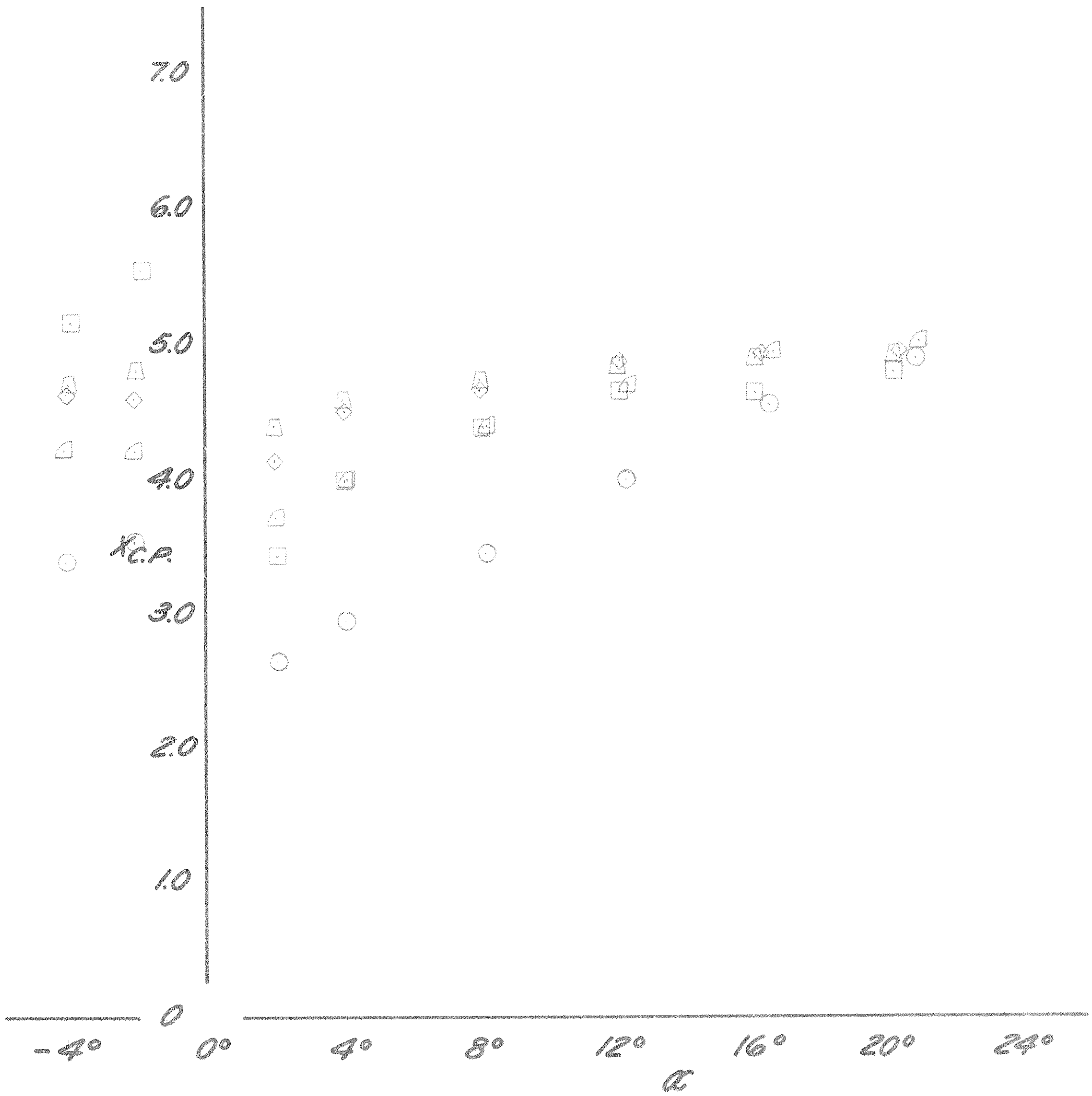
RUN	MACH
⊙ 55	1.32
63	2.01
◇ 52	3.01
△ 44	3.98
⊡ 41	4.76




CONFIG. 170
GRIT #36 Φ=0°
RUN MACH
55 1.32
63 2.01
52 3.01
44 3.98
41 4.76
1.4
1.2
1.0
0.8
C_X
0.6
0.4
0.2
0
-4°
0°
4°
8°
12°
16°
20°
24°
α

CONFIG. 170
GRIT #36 $\phi = 0°$

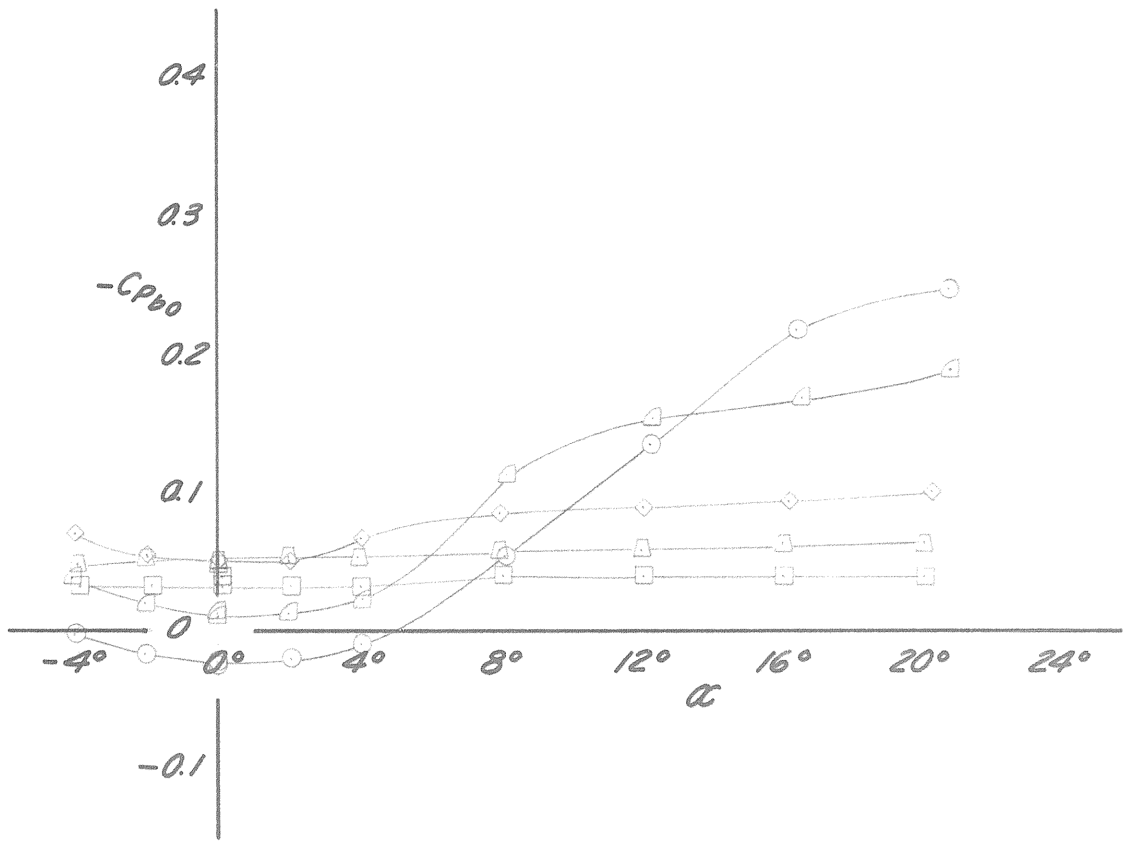
RUN	MACH
⊙ 55	1.32
63	2.01
◇ 52	3.01
△ 44	3.98
⊡ 41	4.76



SWT 20-308

CONFIG. 170
GRIT #36 $\phi = 0°$

RUN	MACH
⊙ 55	1.32
63	2.01
◇ 52	3.01
△ 44	3.98
⊡ 41	4.76



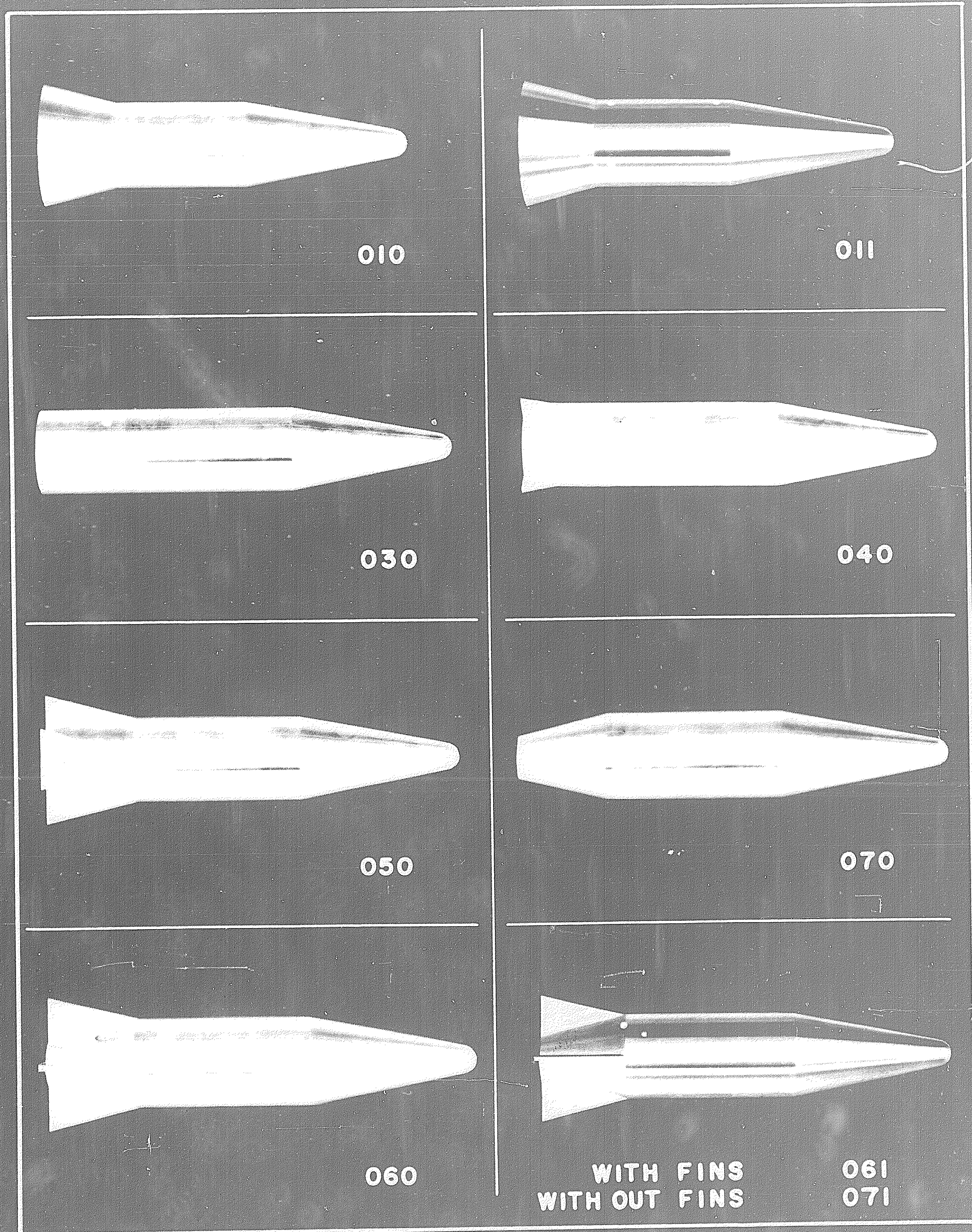


FIGURE I. VARIOUS MODELS TESTED

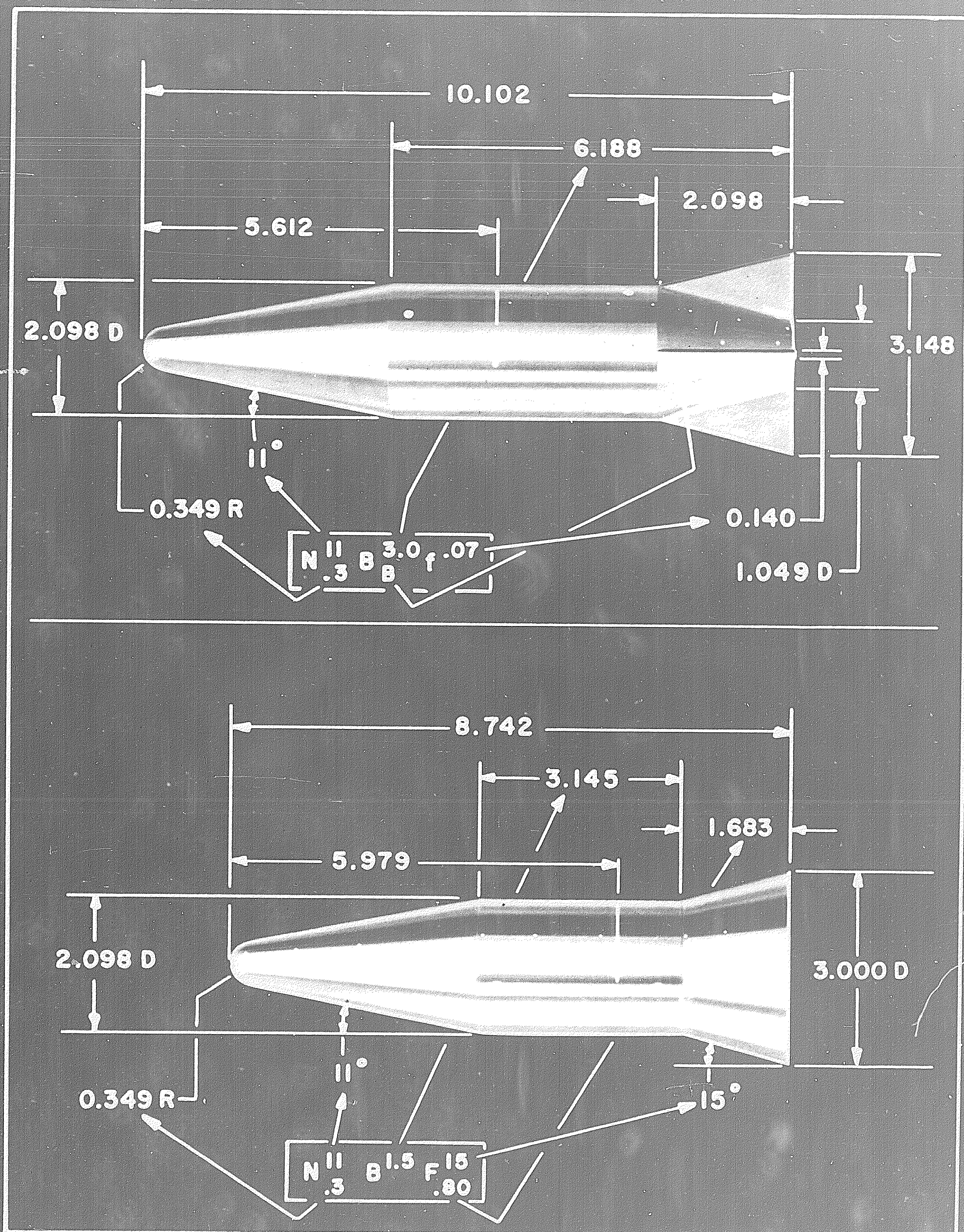


FIGURE 2. MODEL DIMENSIONS AND CONFIGURATION NOMENCLATURE

[redacted]

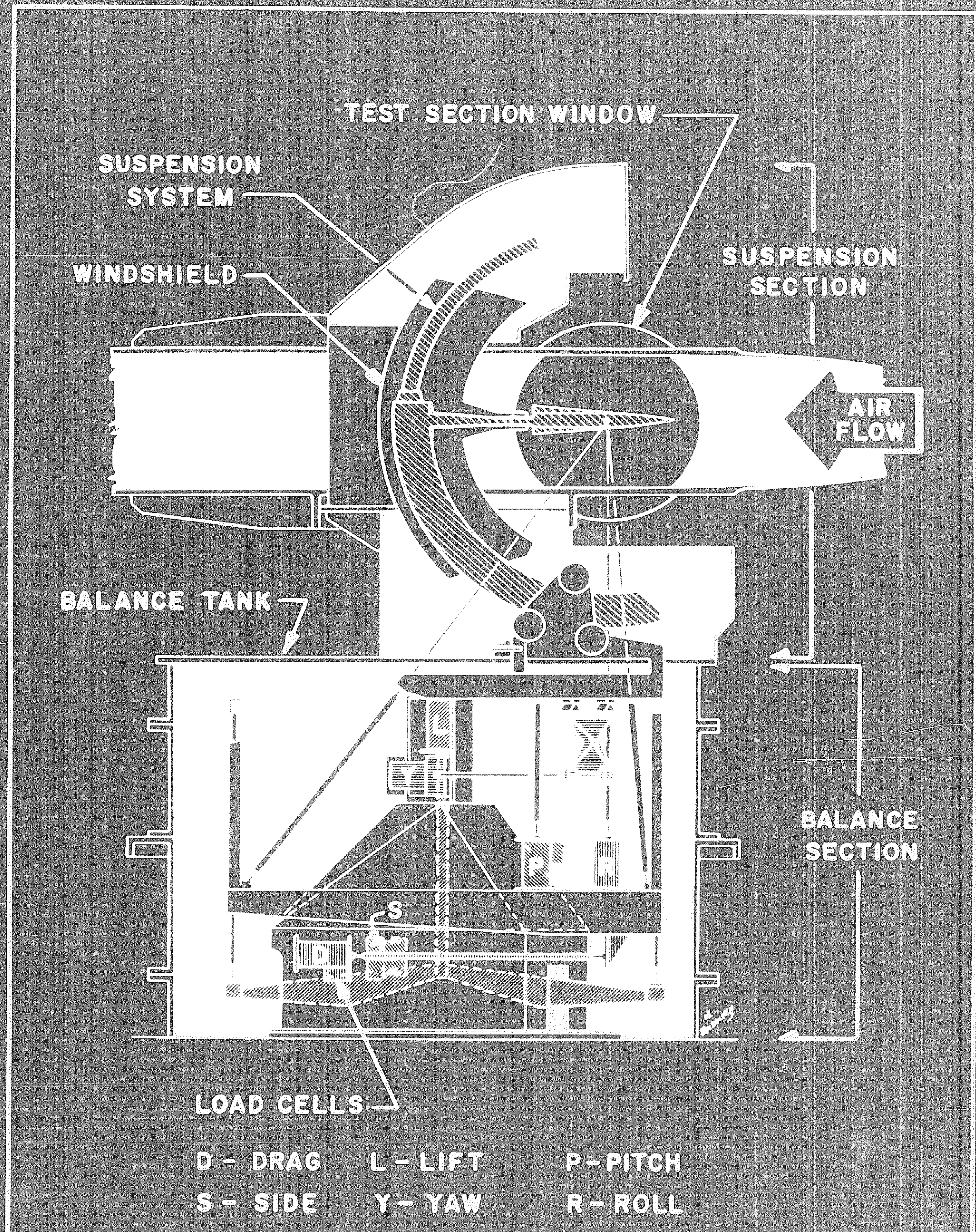


FIGURE 3. THE SIX-COMPONENT EXTERNAL BALANCE AND SUPPORT SYSTEM

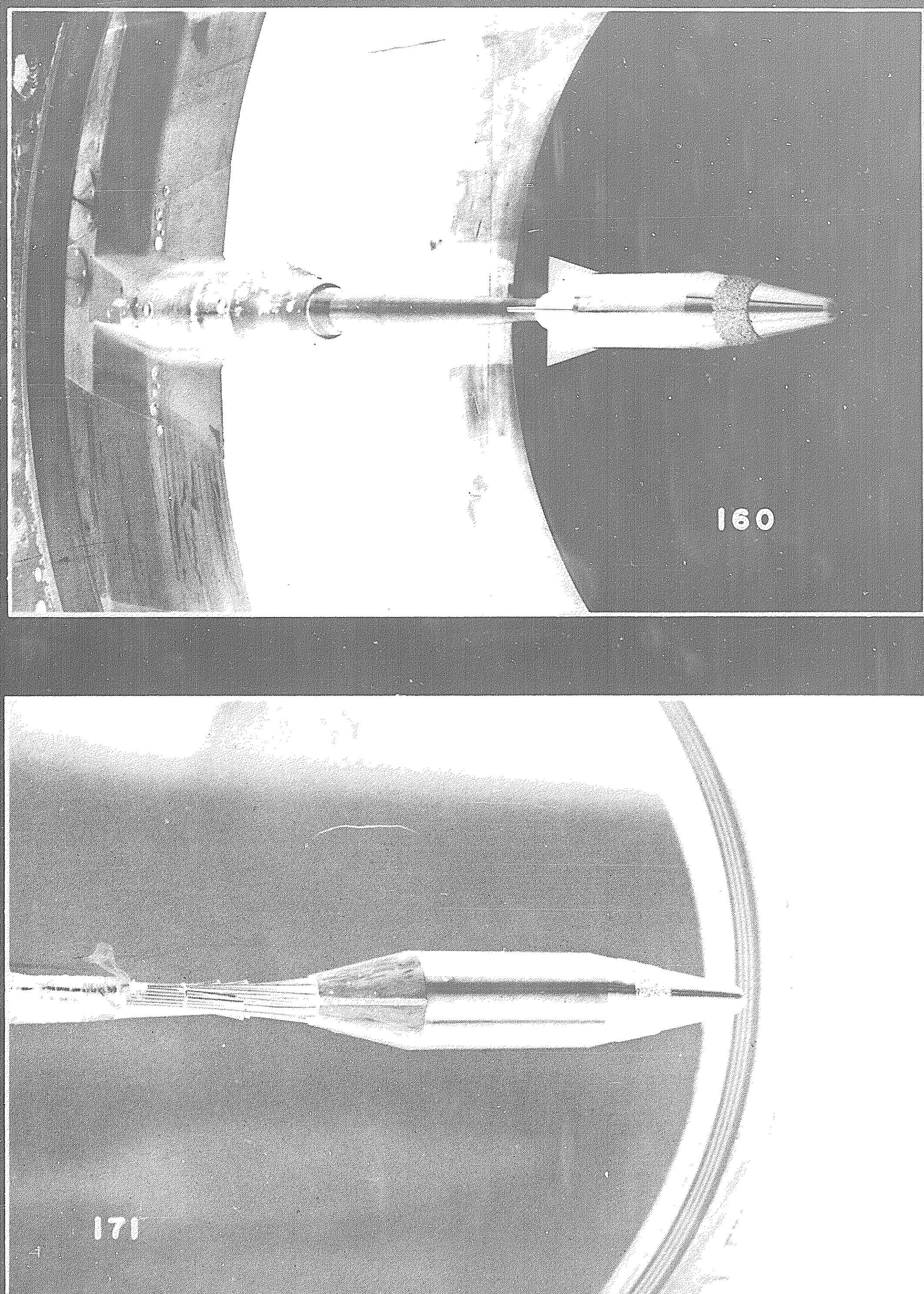


FIGURE 4. INSTALLATION OF MODEL CONFIGURATIONS 160 AND 171

[redacted]

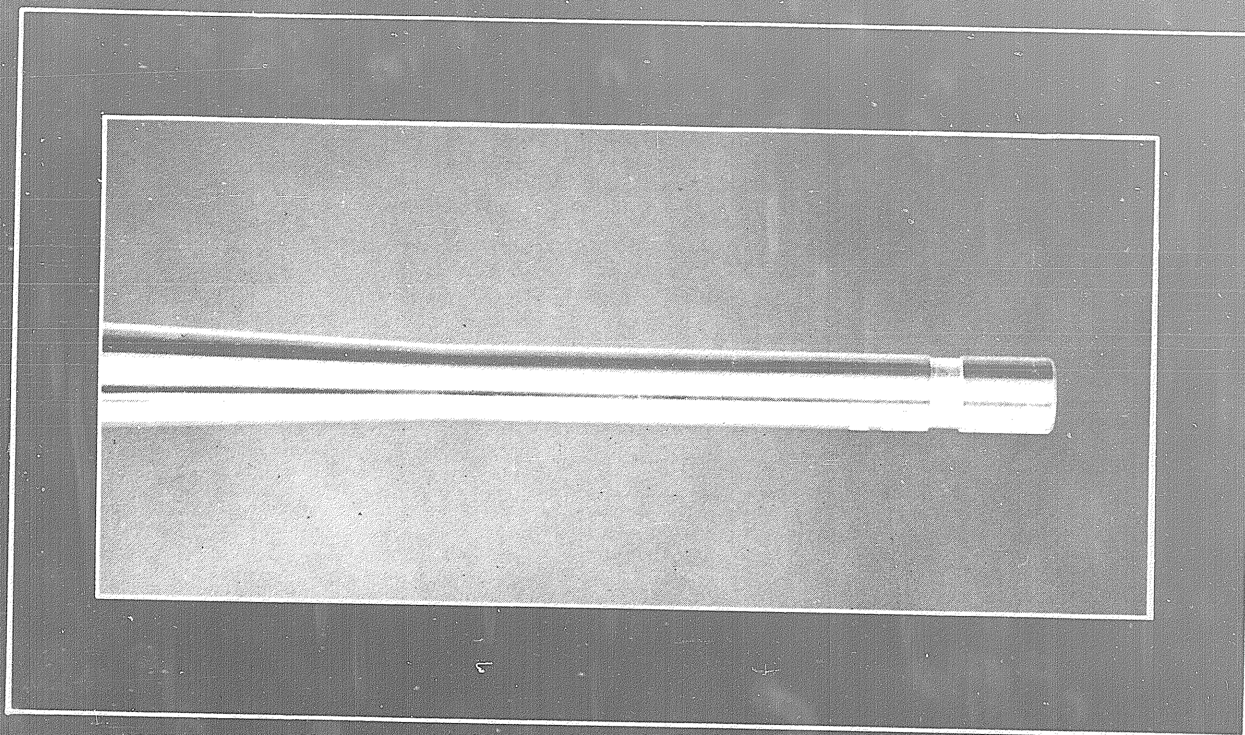


FIGURE 5. MODEL SUPPORT STING

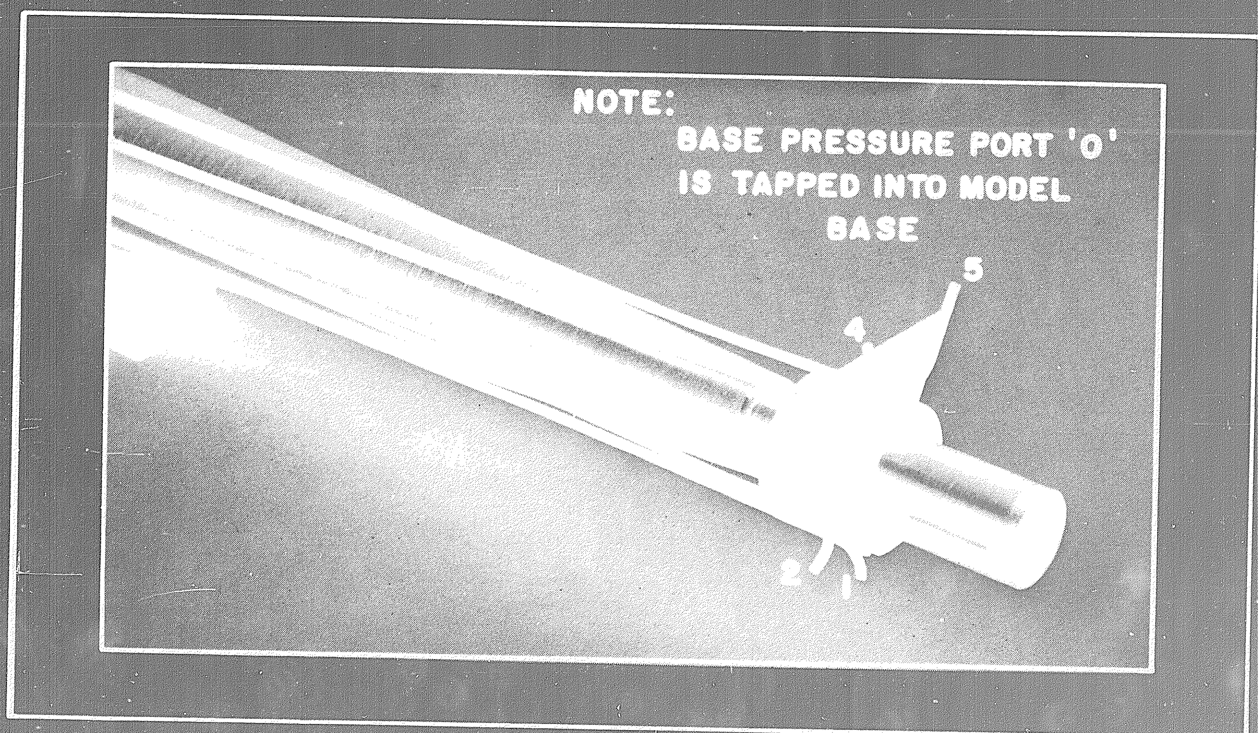


FIGURE 6. BASE PRESSURE RAKE

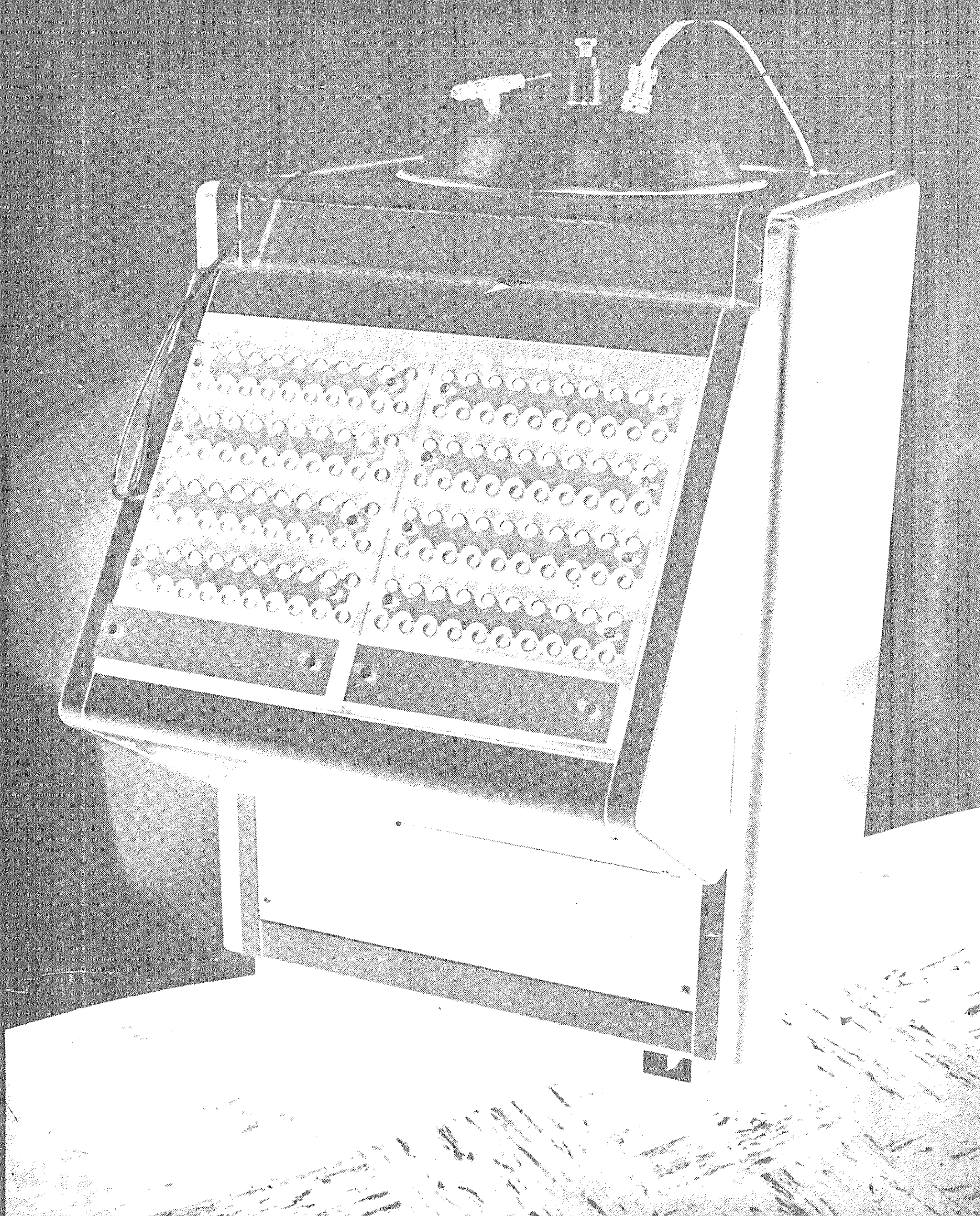


FIGURE 7. MPMS SCANNER UNIT

[redacted]

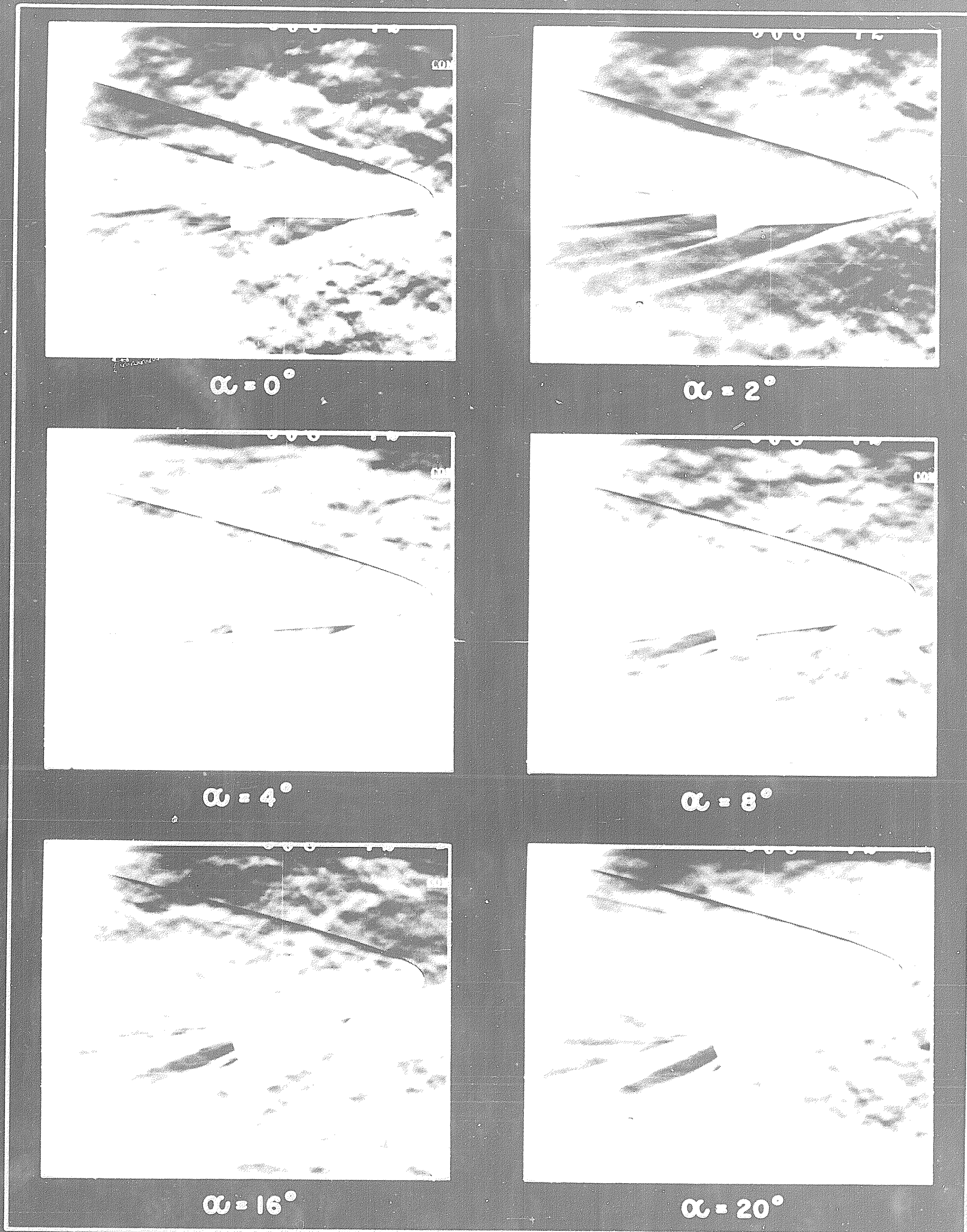


FIGURE 8. SCHLIEREN PHOTOS OF CONFIGURATION 040 AT M = 4.76

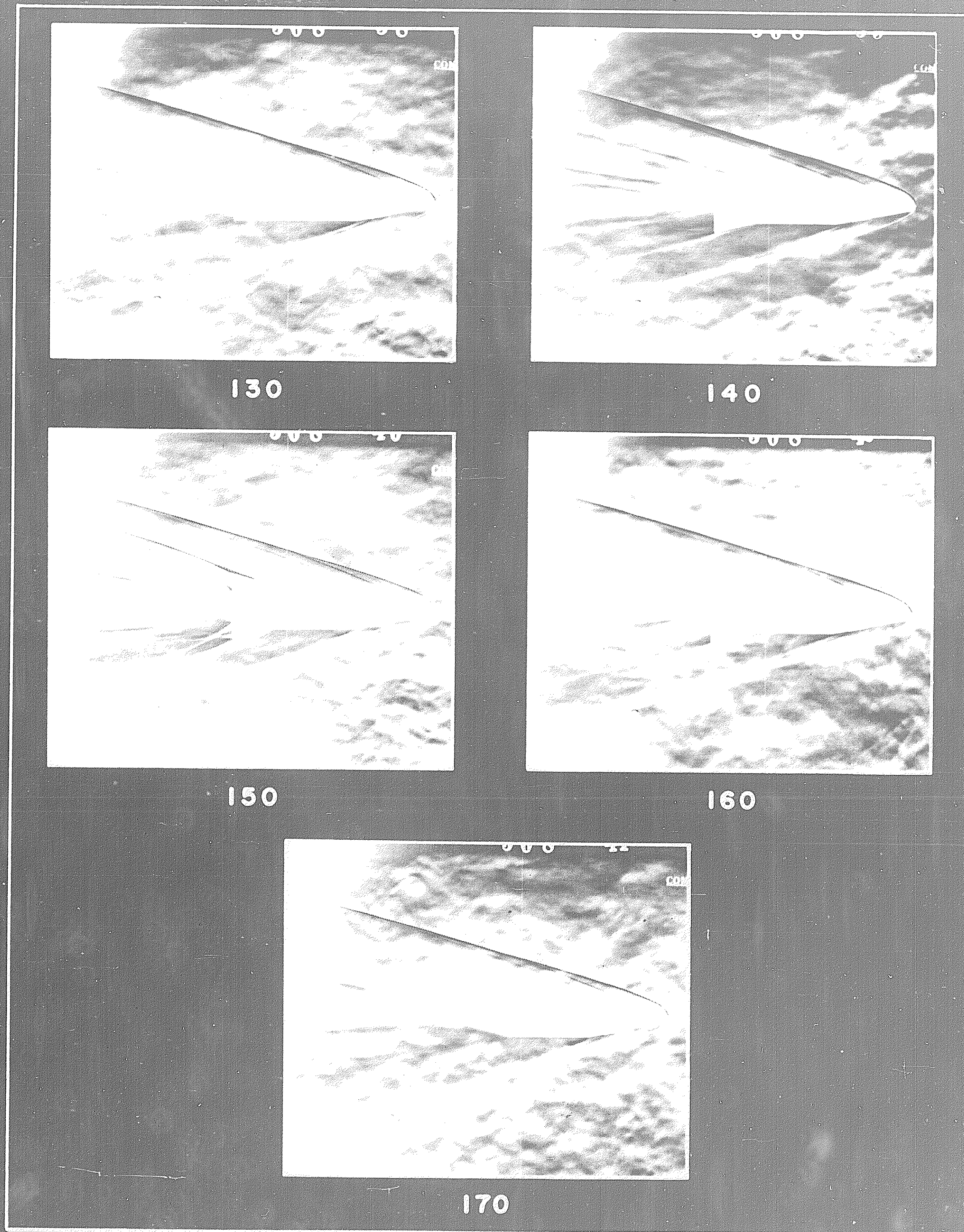
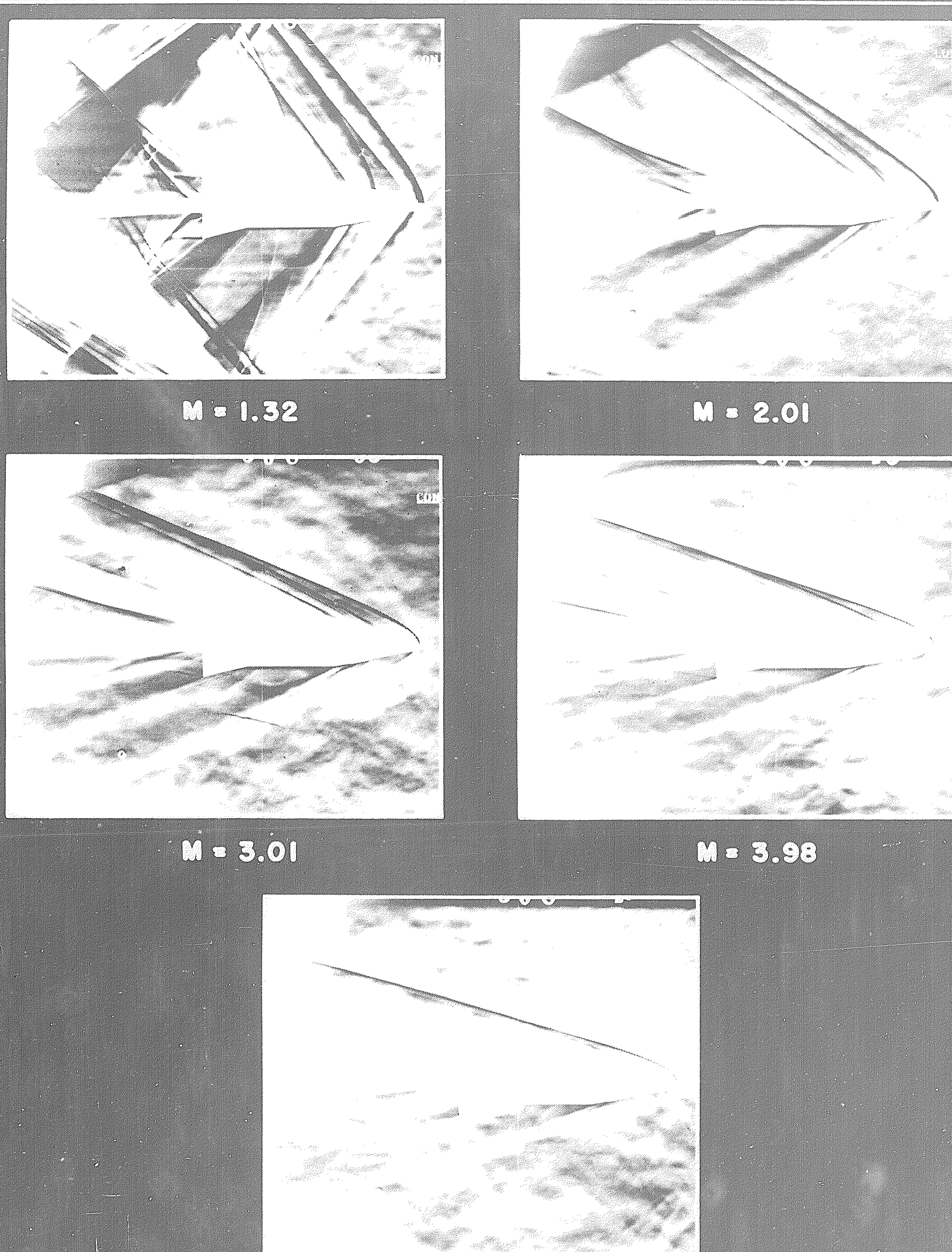


FIGURE 9. SCHLIEREN PHOTOS OF SEVERAL CONFIGURATIONS AT
$M = 4.76$, $\alpha = 0°$



M = 1.32

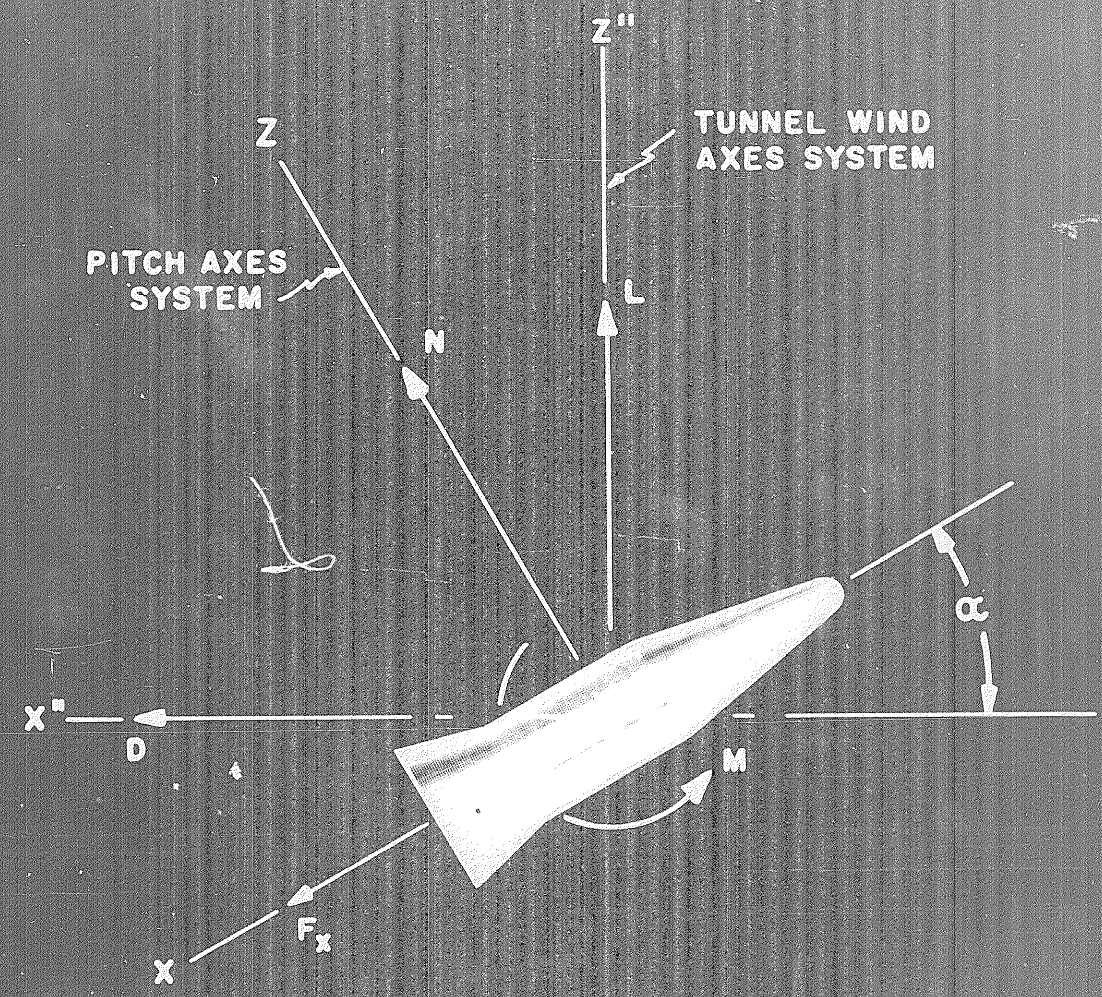
M = 2.01

M = 3.01

M = 3.98

M = 4.76

FIGURE 10. SCHLIEREN PHOTOS OF CONFIGURATION 160 AT FIVE MACH NUMBERS, $\alpha = 0°$



NOTE:
ARROWS INDICATE POSITIVE DIRECTIONS OF FORCES, MOMENTS, ATTITUDE AND AXES

FIGURE 11. SIGN CONVENTIONS